Cold LC Accelerator Update

Hasan Padamsee, for the TESLA Collaboration

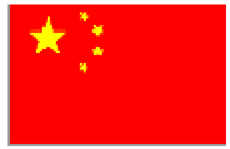
Outline

- News on Gradients
- Industrial Participation
- Momentum of cold technology

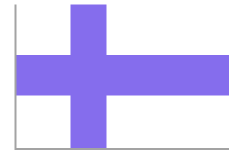
TESLA Collaboration

CIEMAT- Spain (Madrid)

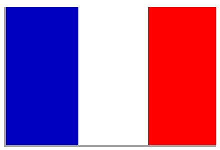
Yerevan Physics Institute



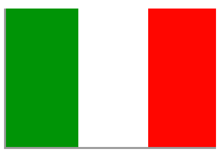
IHEP, BeijingTsinghua University



Institute of Physics, Helsinki

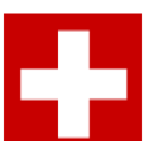


DSM/DAPNIA, Saclay
IN2P3/IPN, Orsay
IN2P3/LAL, Orsay



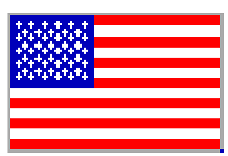
INFN, Frascati
INFN, Legnaro
INFN, Milano
Univ.Roma II

BINP, Novosibirsk
BINP, Protvino
IHEP, Protvino
INR, Troitsk
JINR Dubna
MEPhI, Moscow
ITEP, Moscow

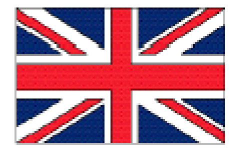


Paul Scherrer Institut, Villingen

BESSY, Berlin
DESY, Hamburg
Frankfurt University
FZ Karlsruhe
GKSS Research Centre
Hahn-Meitner-Institut Berlin
Hamburg University
Max Born Institute, Berlin
Rostock University
RWTH, Aachen
TU, Berlin
TU, Darmstadt
TU, Dresden
Wuppertal University



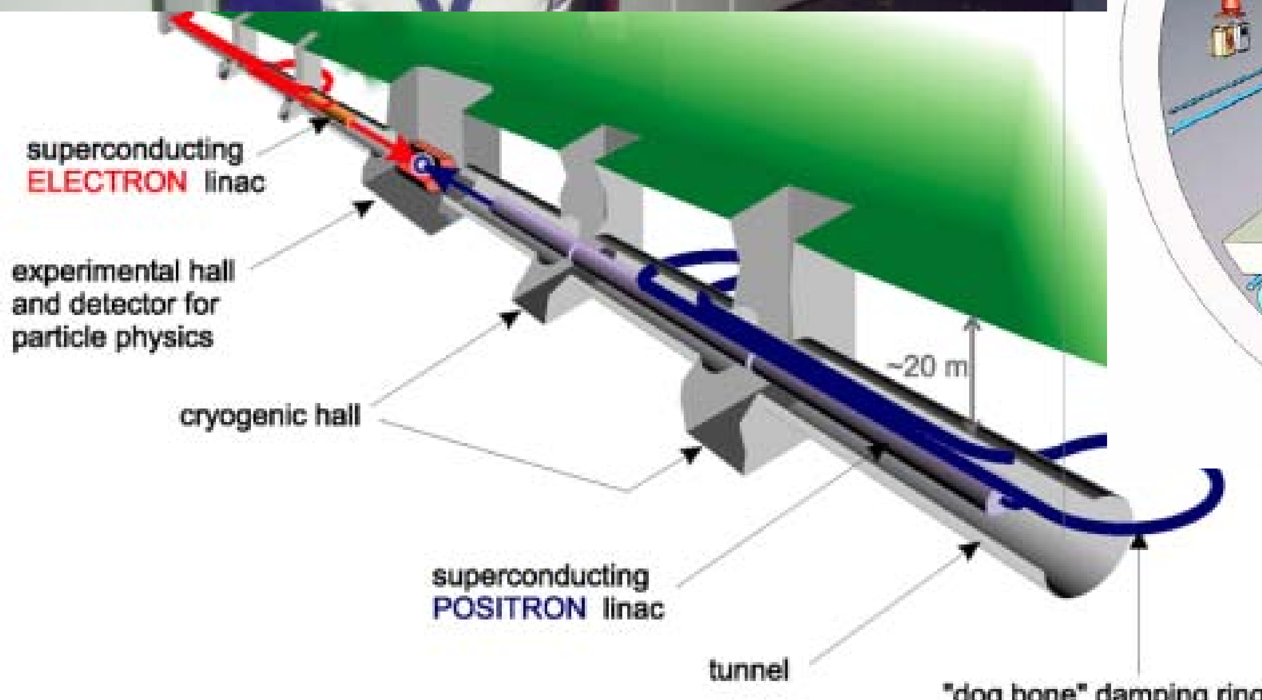
APS/Argonne, Chicago, IL
Cornell University, Ithaca, NY
Fermilab, Batavia, IL
Thomas Jefferson National Laboratory, Newport News, VA
UCLA Dep.of Physics, Los Angeles, LA



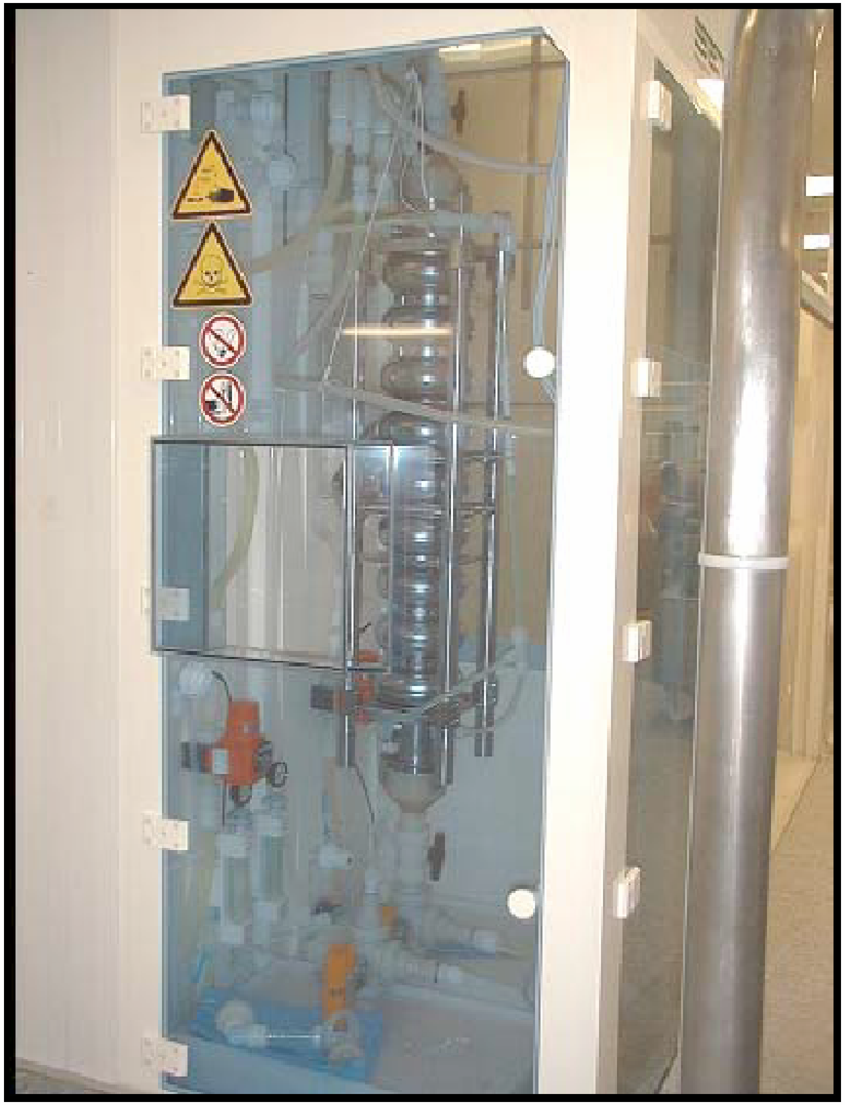
CCLRC, Daresbury & Rutherford Appleton

DMCS Technical University, Lodz Faculty of Physics Warsaw University
High Pressure Reaserch Center "UNIPRESS" PAS, Warsaw
Inst. of Nuclear Physics, Cracow
Inst. of Physics Polish Acad. of Science, Warsaw
ISE Technical University, Warsaw
Polish Atomic Energy Agency, Warsaw
Soltan Inst. for Nuclear Studies, Otwock-Swierk
Univ. of Mining & Metallurgy, Cracow


TESLA 9-cell


superconducting
ELECTRON linac
experimental hall
and detector for
particle physics
cryogenic hall
~20 m
superconducting
POSITRON linac
tunnel
"dog bone" damping ring

Old Treatment: BCP

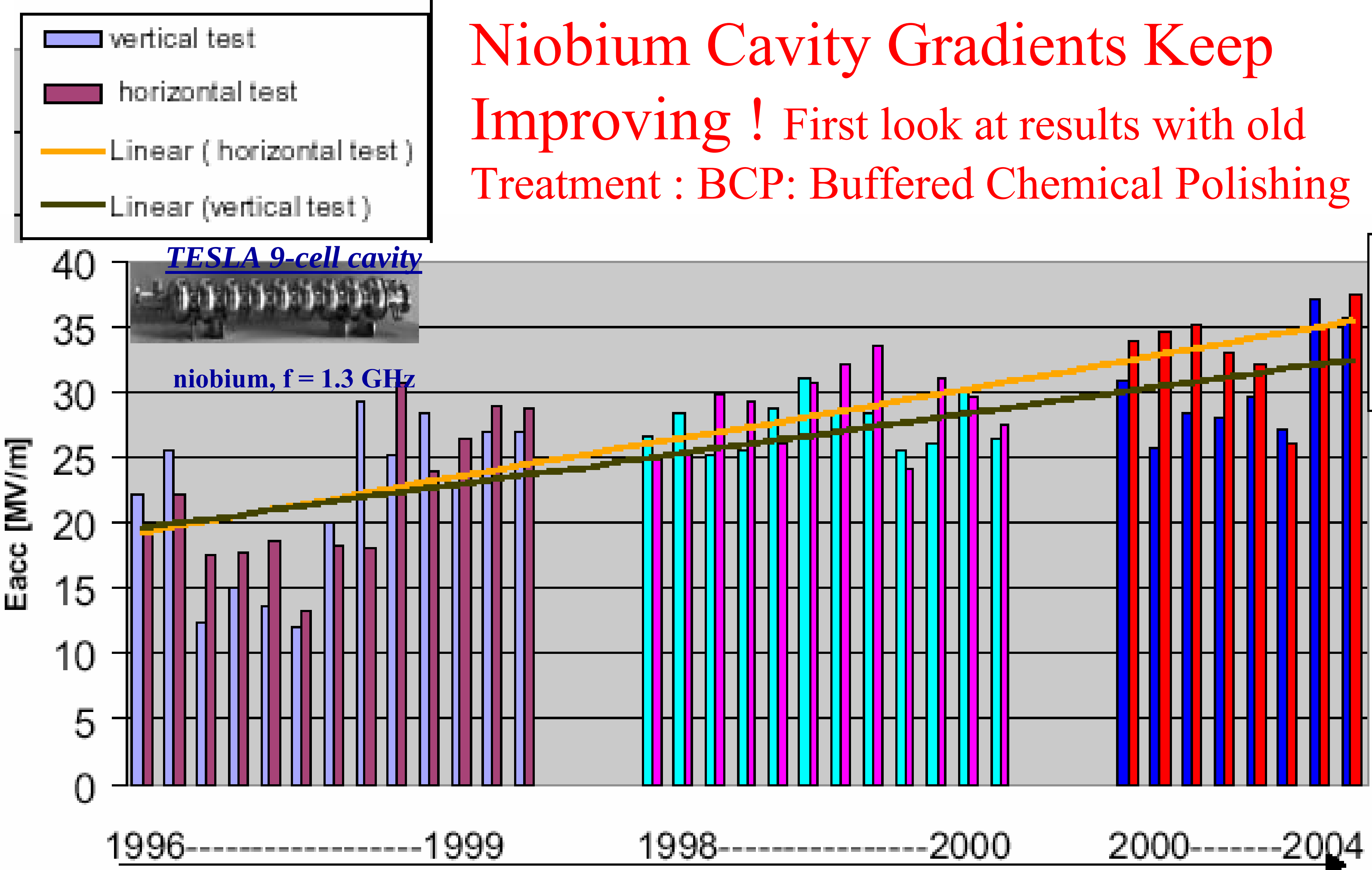


View on a cavity during chemical treatment inside the class 10000 cleanroom

Niobium Cavity Gradients Keep Improving ! First look at results with old Treatment : BCP: Buffered Chemical Polishing

Later: New Treatment

Niobium Cavity Gradients Keep Improving ! First look at results with old Treatment : BCP: Buffered Chemical Polishing



first production
average gradient
21,6 MV/m vertical
21,7 MV/m horizontal

second production
average gradient
27,5 MV/m vertical
28,7 MV/m horizontal

third production
average gradient
30,3 MV/m vertical
33,4 MV/m horizonta

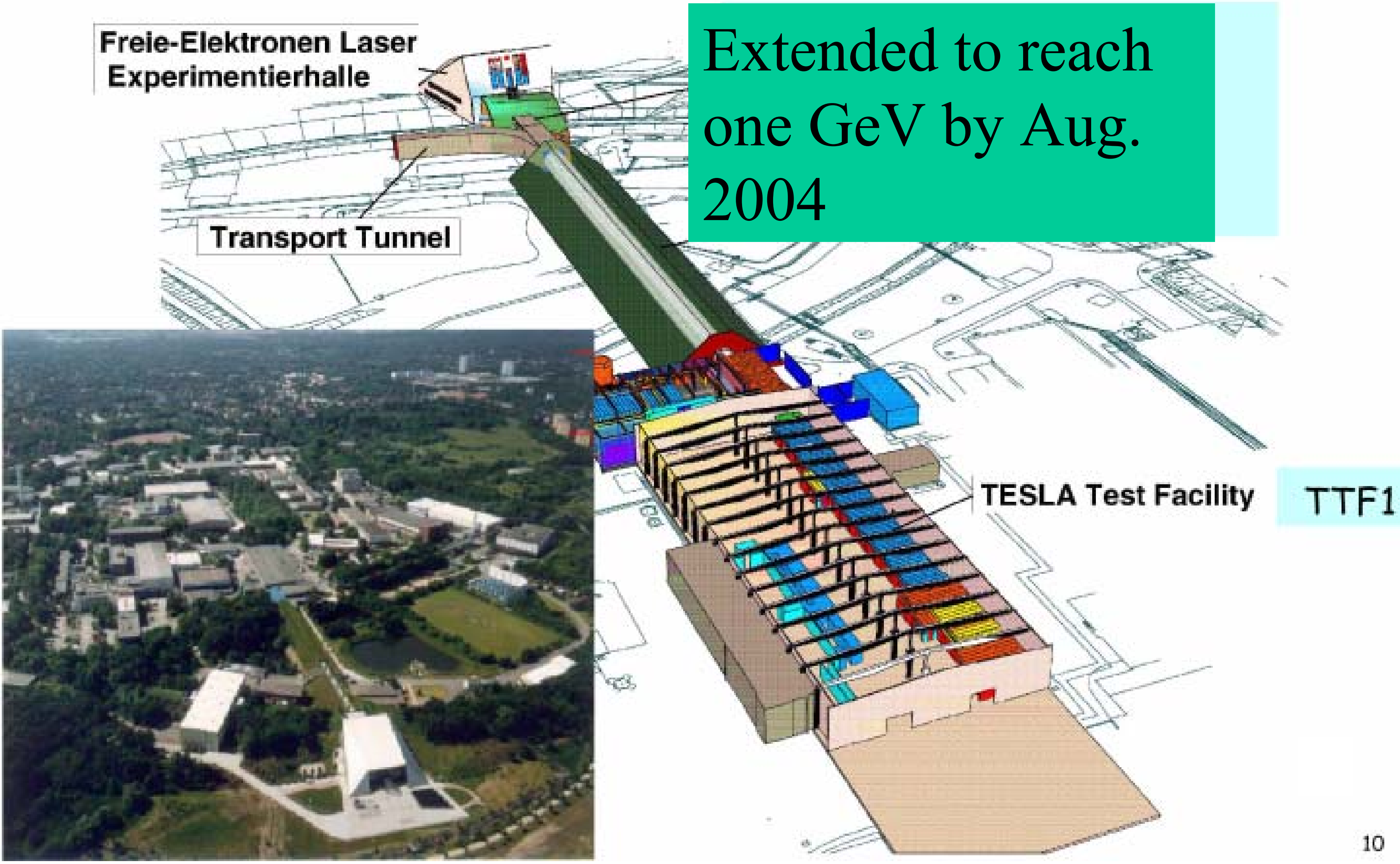
=> Procedures well established …90 cavities tested

Preparation of TESLA Cavities

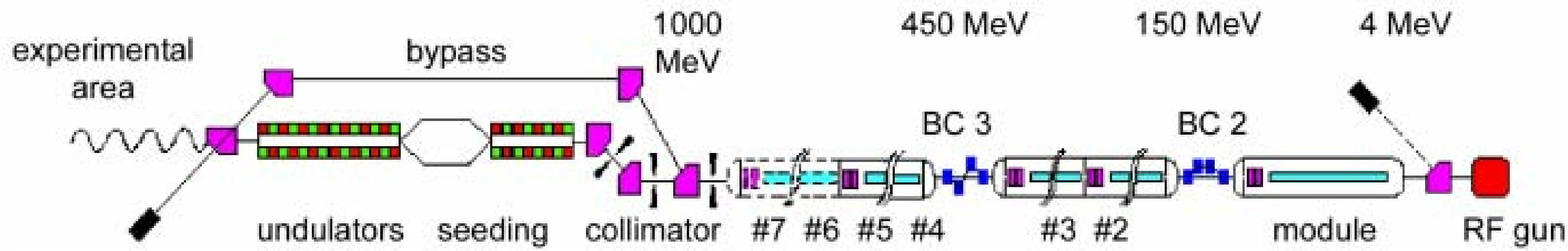
Large experience base, 10 cryomodules assembled (80 meters active)……..Integrated cold time: 10 module-years

Commissioning News from TTF II

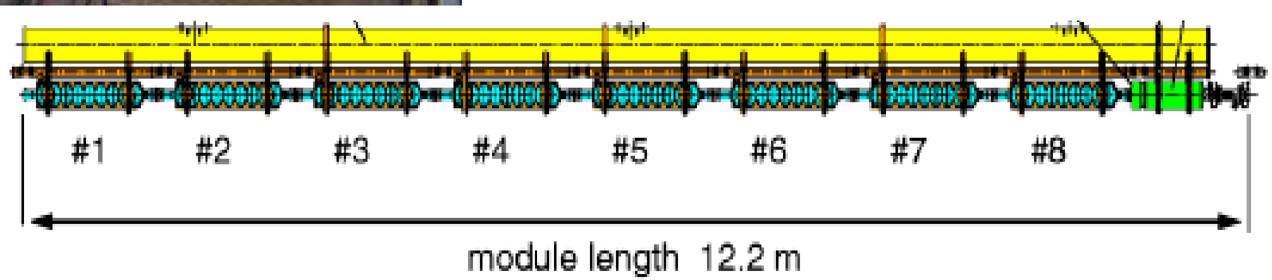
Extended to reach one GeV by Aug. 2004



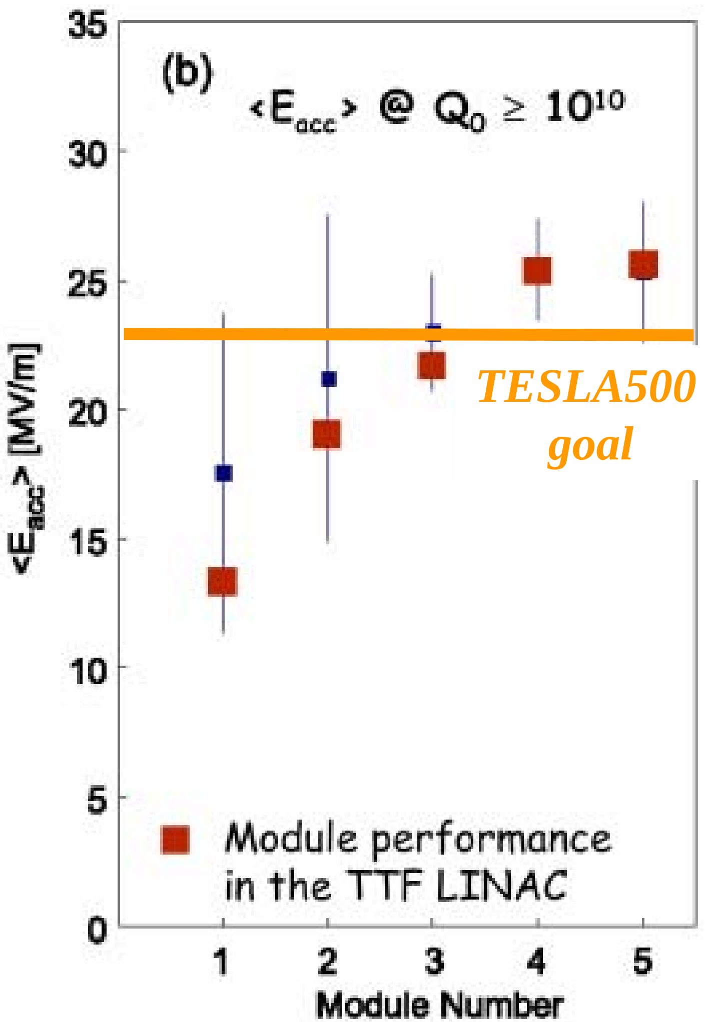
Cryomodule Gradients Also Rising

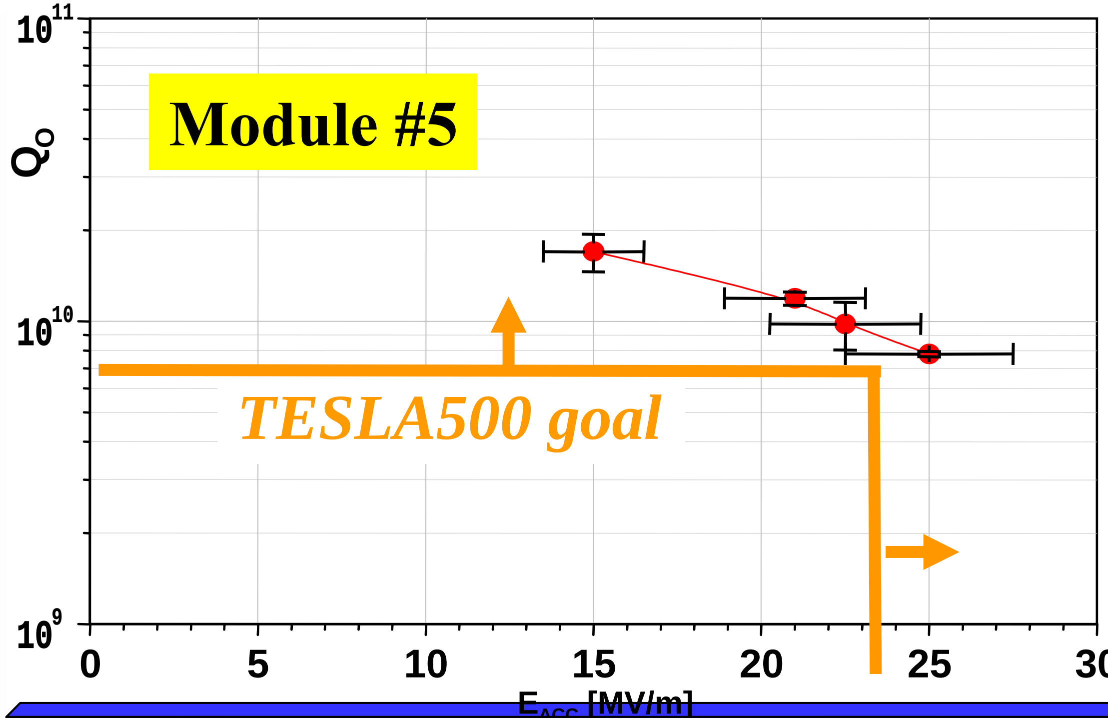


- Cryomodules 4 and 5 with <u>16 active meters</u> of cavities installed and tested with high gradients to satisfy 500 GeV performance for gradient, alignment and dark current .



TTF Cavity-Module Performance (Pulsed Operation)





- **High gradient cw performance preserved during cavity installation into linac.**
- **BCP cavity modules #4 and #5 exceed TESLA500 performance goal.**

Dark Currents:

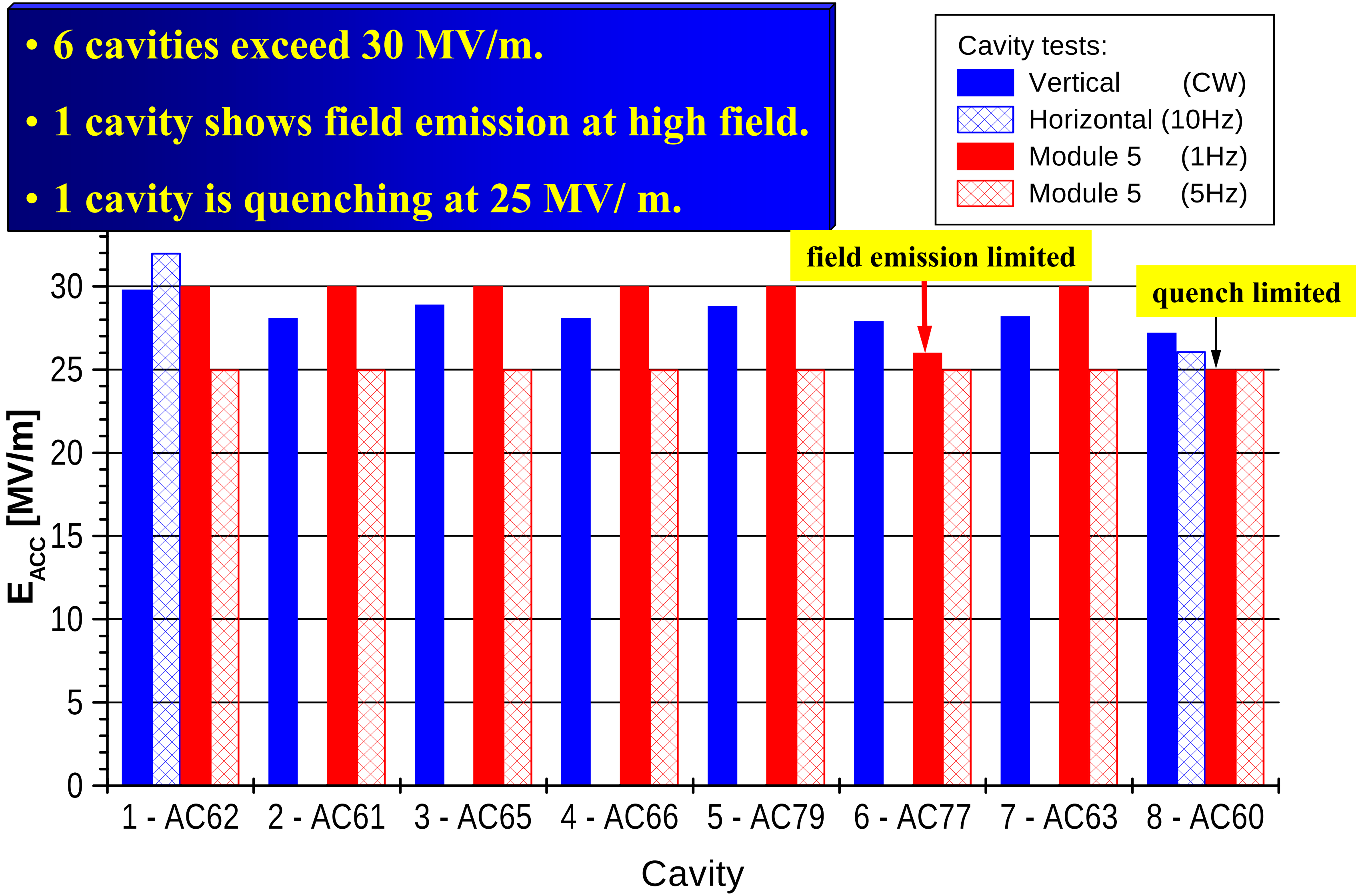
ACC4 15 nA/cavity average (8 cavities on)

ACC5 25 nA/cavity (7 cavities) at 25 MV/m

Acceptable: 70 nA/cavity @ 25 MV/m ≈ 250 mwatt heat load

BCP Cavity Module ACC 5: Cavity Performance

- **6 cavities exceed 30 MV/m.**
- **1 cavity shows field emission at high field.**
- **1 cavity is quenching at 25 MV/ m.**

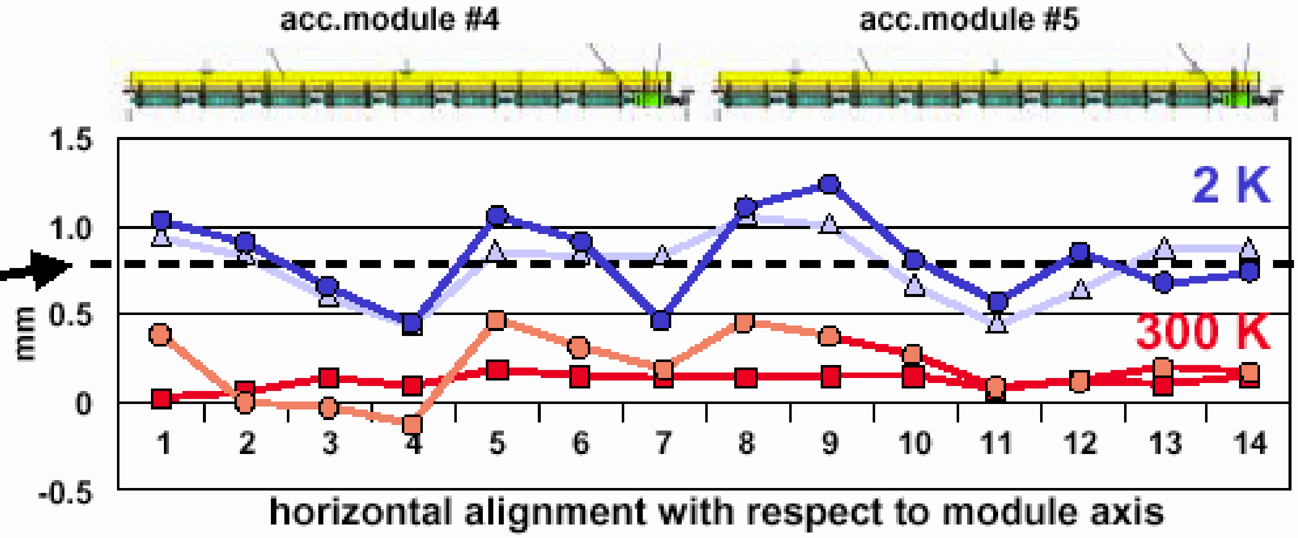


Cavity/Quadrupole Alignments measured using a stretched wire system at 300 K and 2K.

cavity / quad string alignment is measured using a stretched wire system

at warm and at cold temperature

corresponds to a perfectly aligned cavity / quad string



TDR specifications (RMS):

cavities	x/y:	+/-	0.5 mm
	z:	+/-	1 mm
quad/dip	x/y:	+/-	0.3 mm
	z:	+/-	1 mm
	roll:	+/-	0.1 mrad

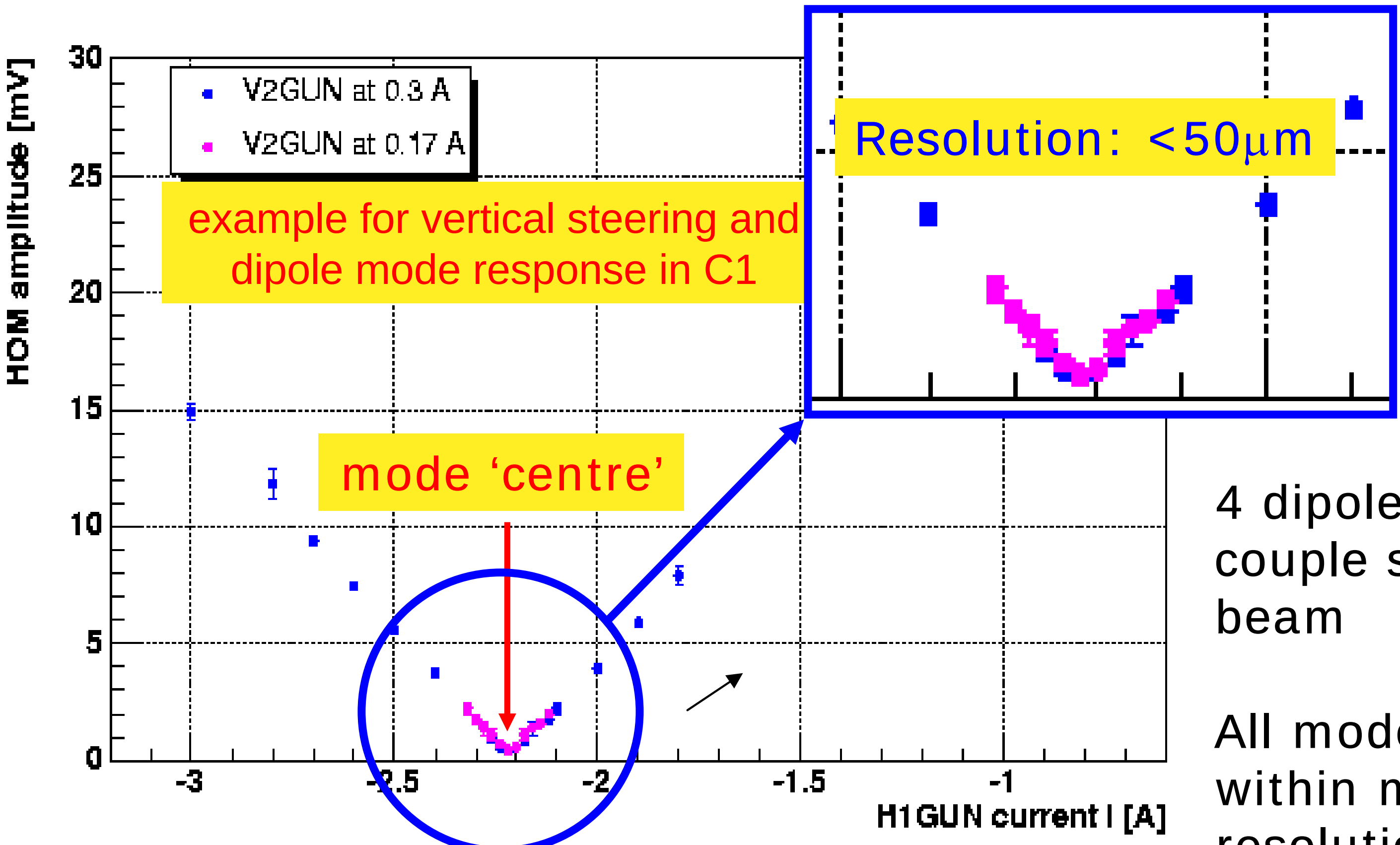
Results (peak):

cavities	x:	+/-	0.35 mm
	y:	+/-	0.25 mm
quad/dip	x:		+ 0.1 / - 0.4 mm
	y:		+ 0.2 / - 0.5 mm

overall module tilt ≈ 0.1 mrad

20-Jun-03	300 K
22-Jul-03	2 K
06-Oct-03	300 K
31-Mar-04	2 K

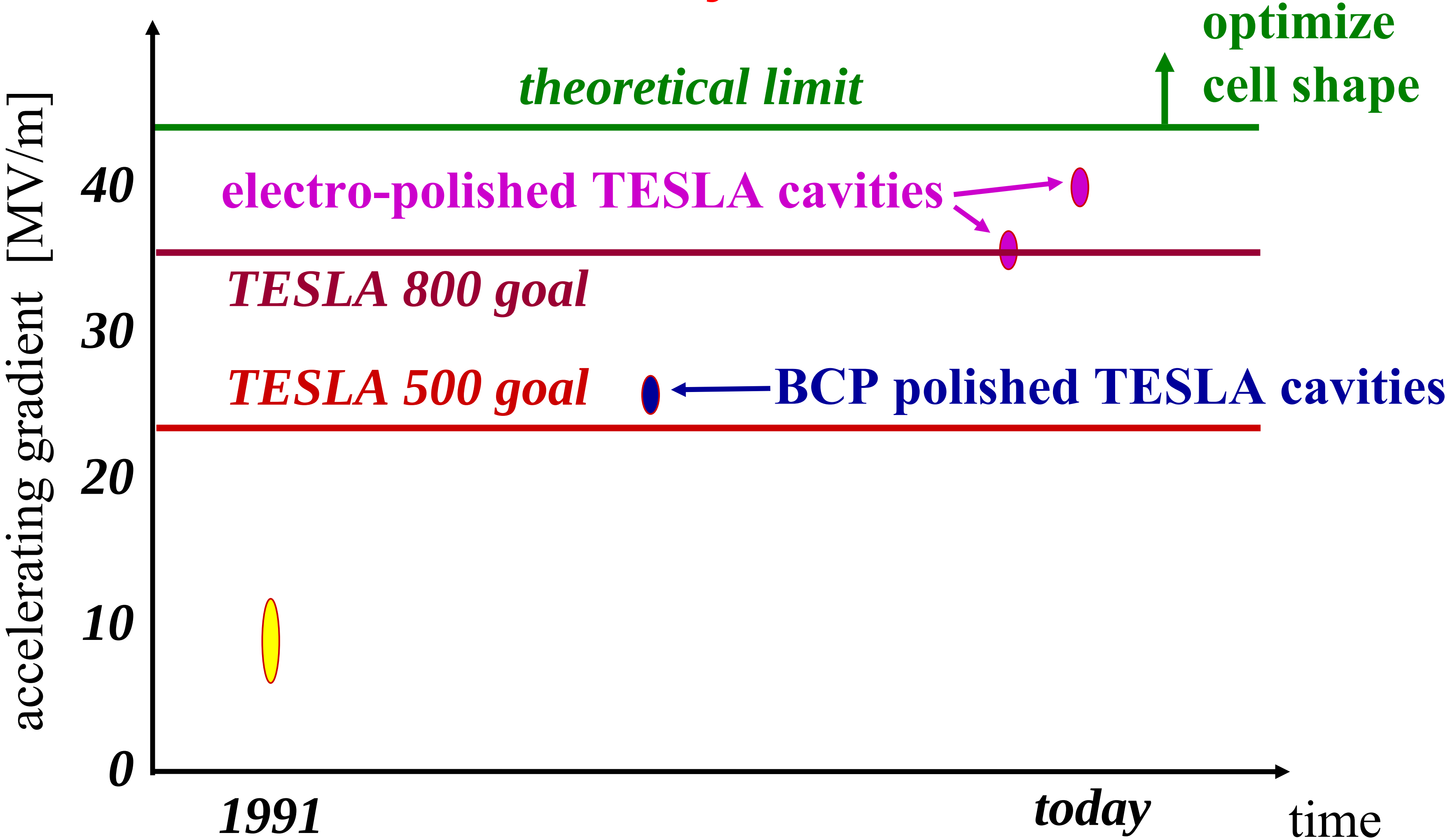
Check Measurement of Beam Position in Cavity using Dipole Mode



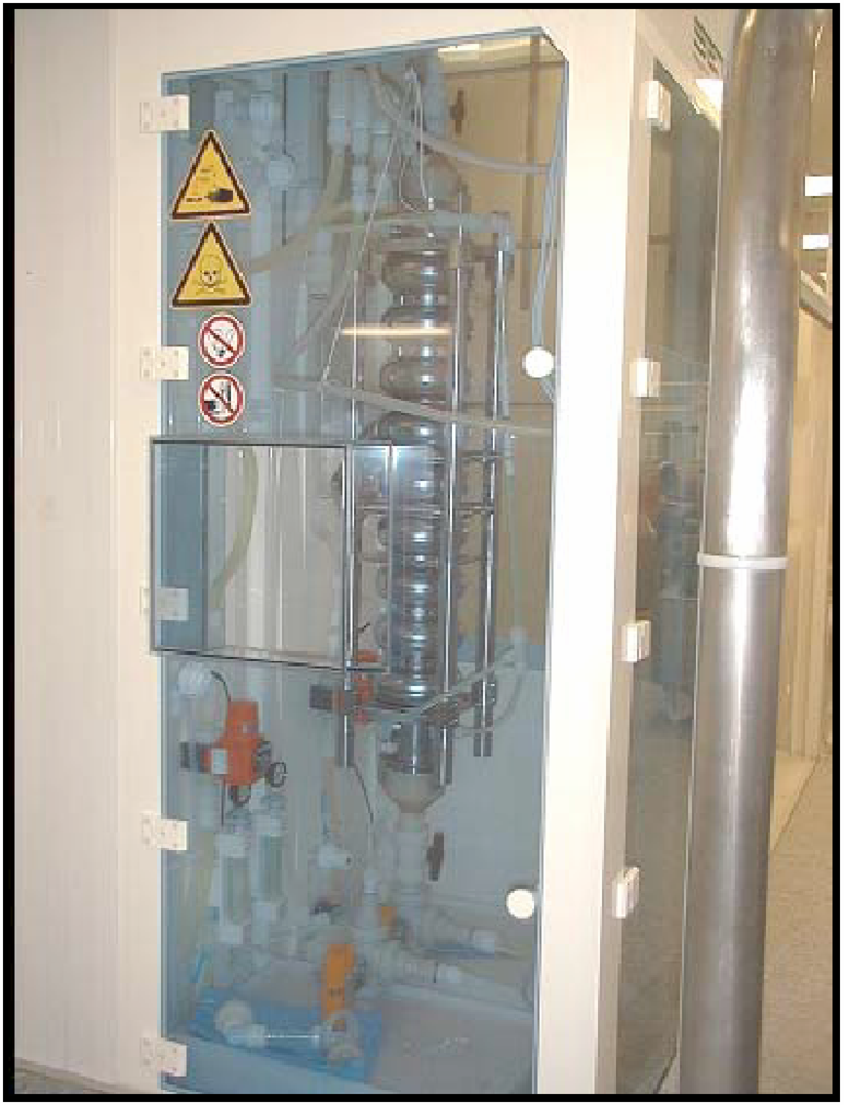
4 dipole modes which couple strongly to the beam

All modes co-axial within measurement resolution (50μm)

What about the upgrade goal of 35 MV/m and beyond?

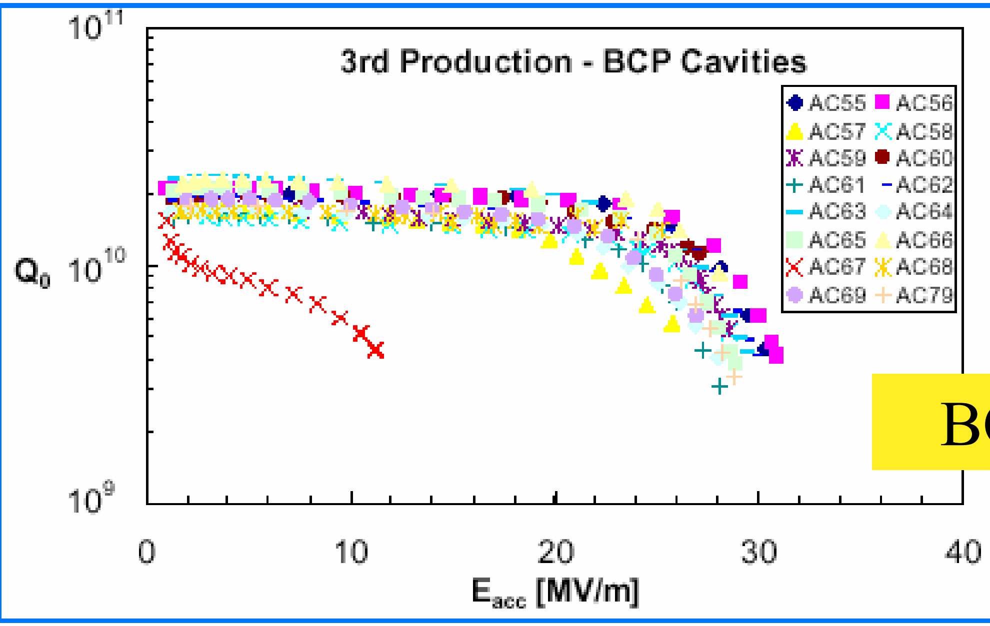


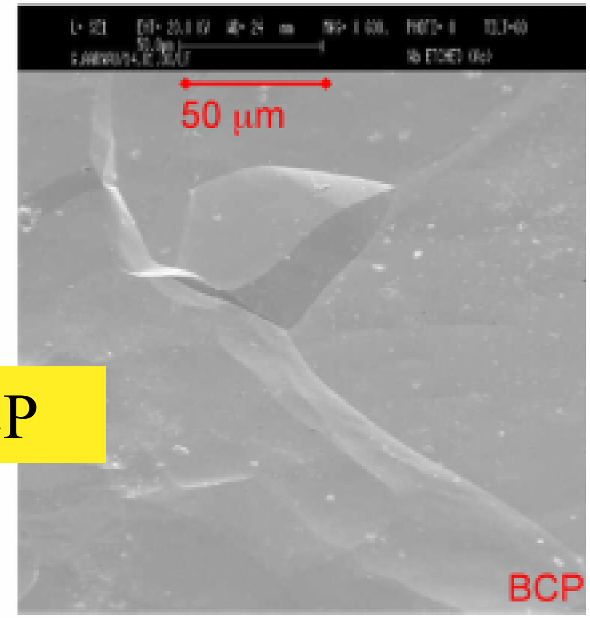
Old Treatment: BCP



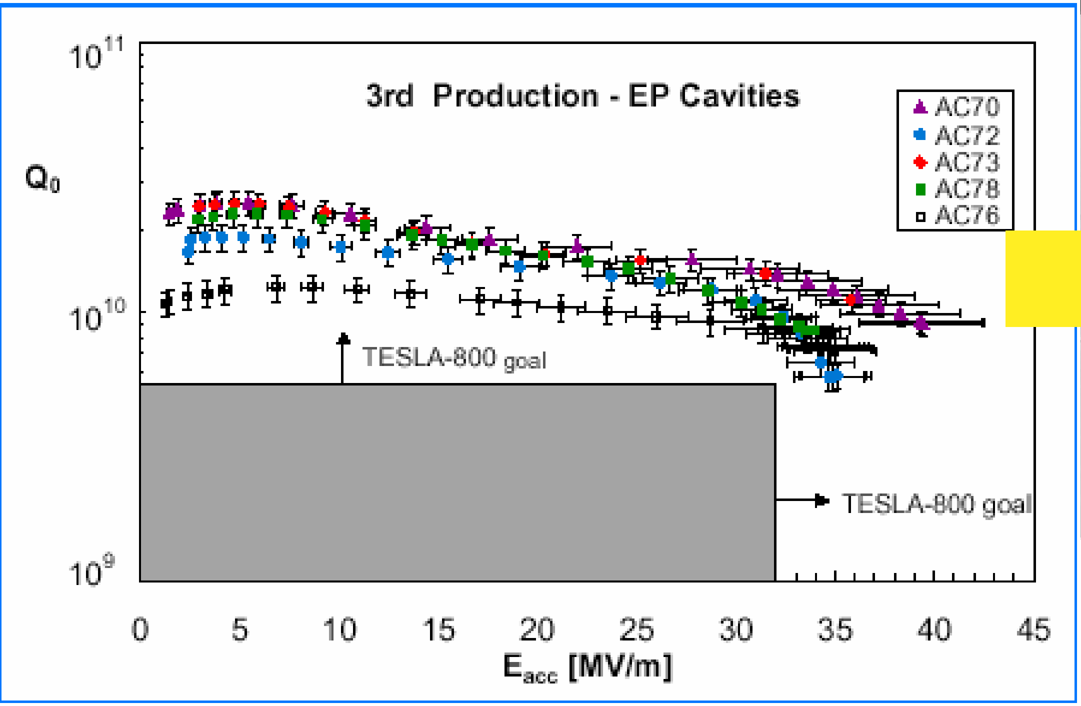
View on a cavity during chemical treatment
inside the class 10000 cleanroom

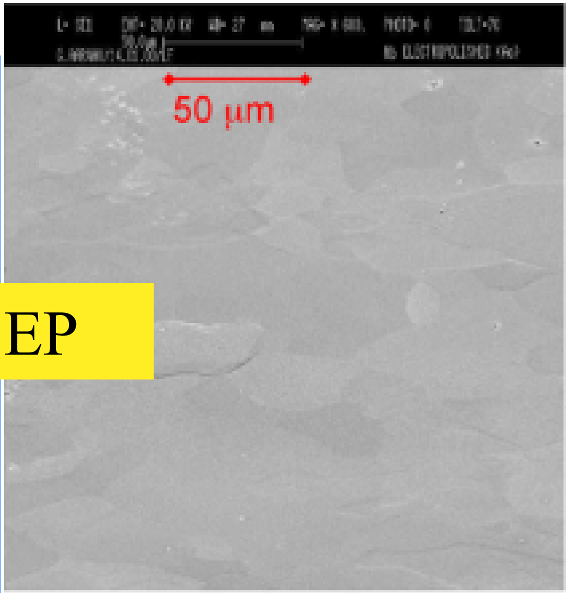
New Treatment Procedures: Electropolishing and 120 C Baking





BCP





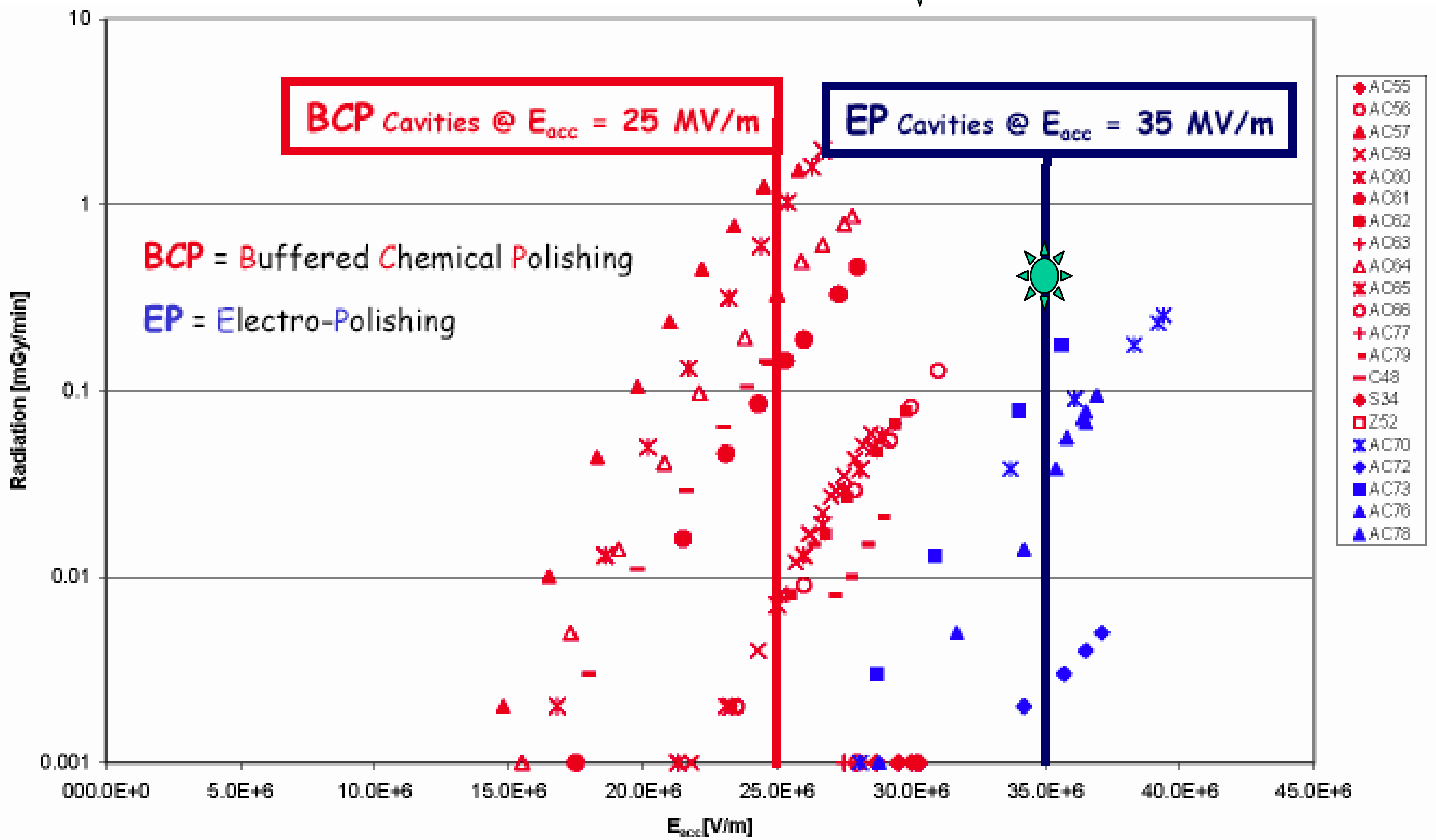
EP

5 cavities tested with EP

Eacc = 35 - 40 MV/m

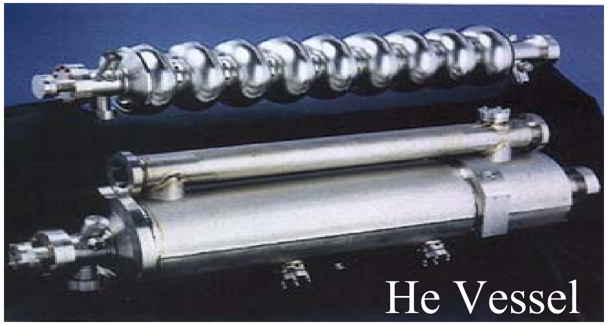
All 5 Electropolished Cavities at 35 MV/m show less radiation than BCP cavities at 25 MV/m.. Cleaner preparaton achieved

50 nA @ 35 MV/m per cavity acceptable ≈ 250 mW per cavity at 35 MV/m, estimated corresponding radiation dose



So far all cavity test results discussed are for bare cavities tested by dunking in a simple vertical dewar of liquid helium

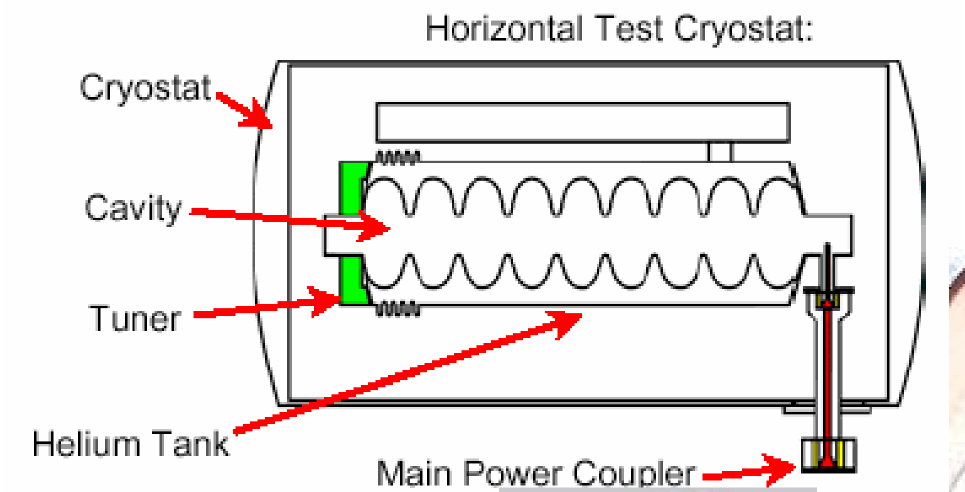
-> vertical test

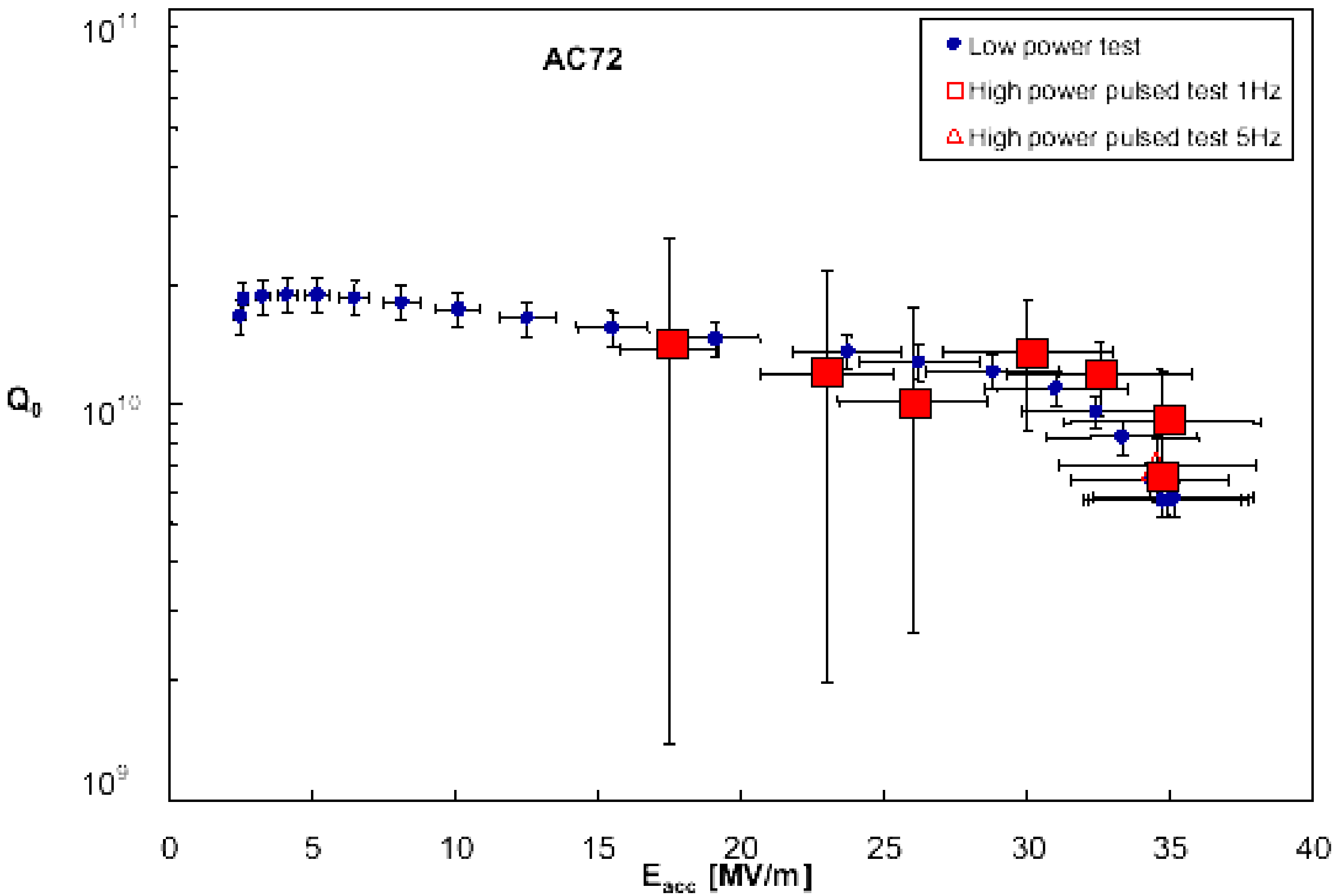


Fully Dressed Cavity

Single Cavity Cryomodule

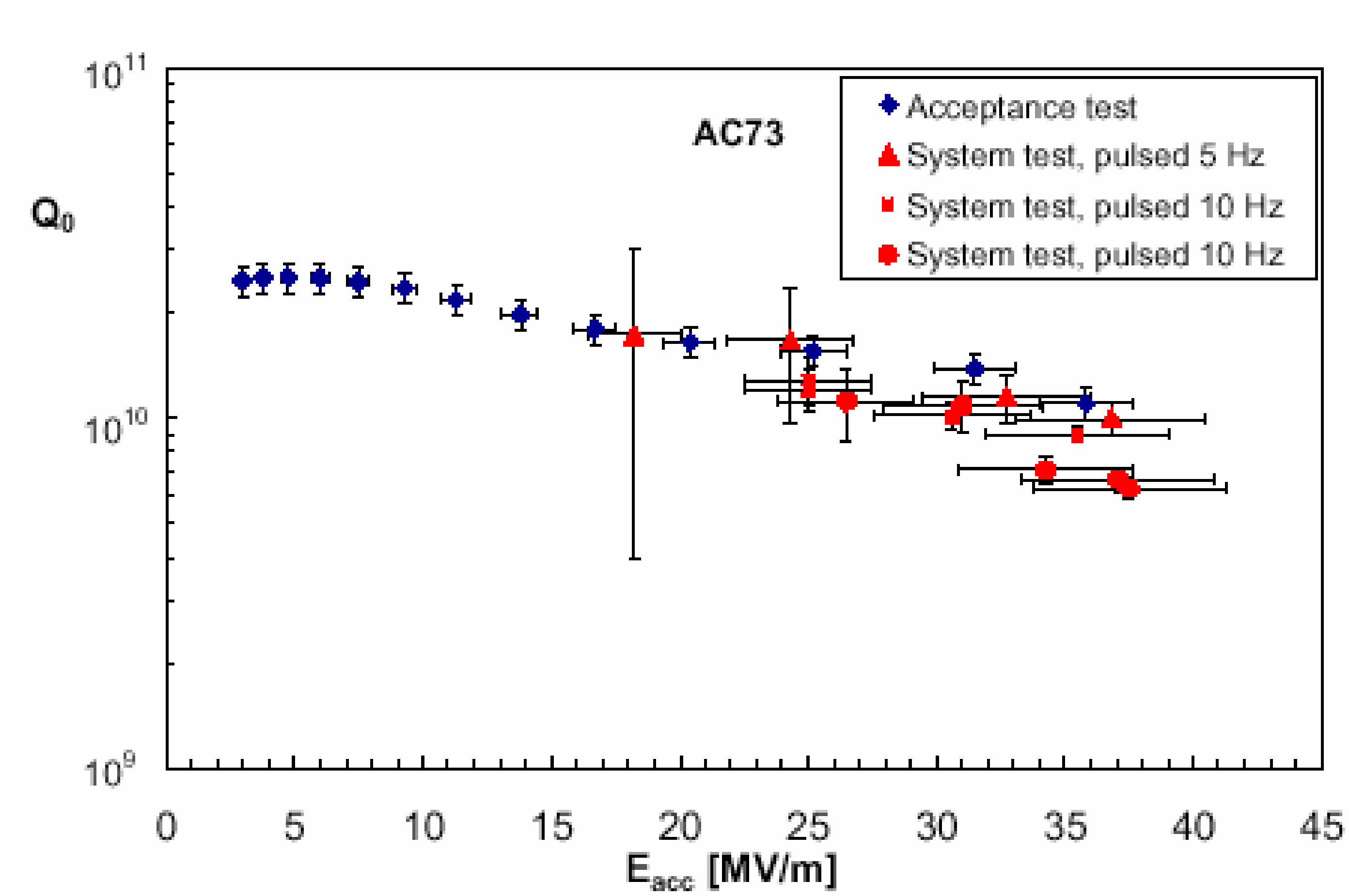
Full Power (500 kW) Test





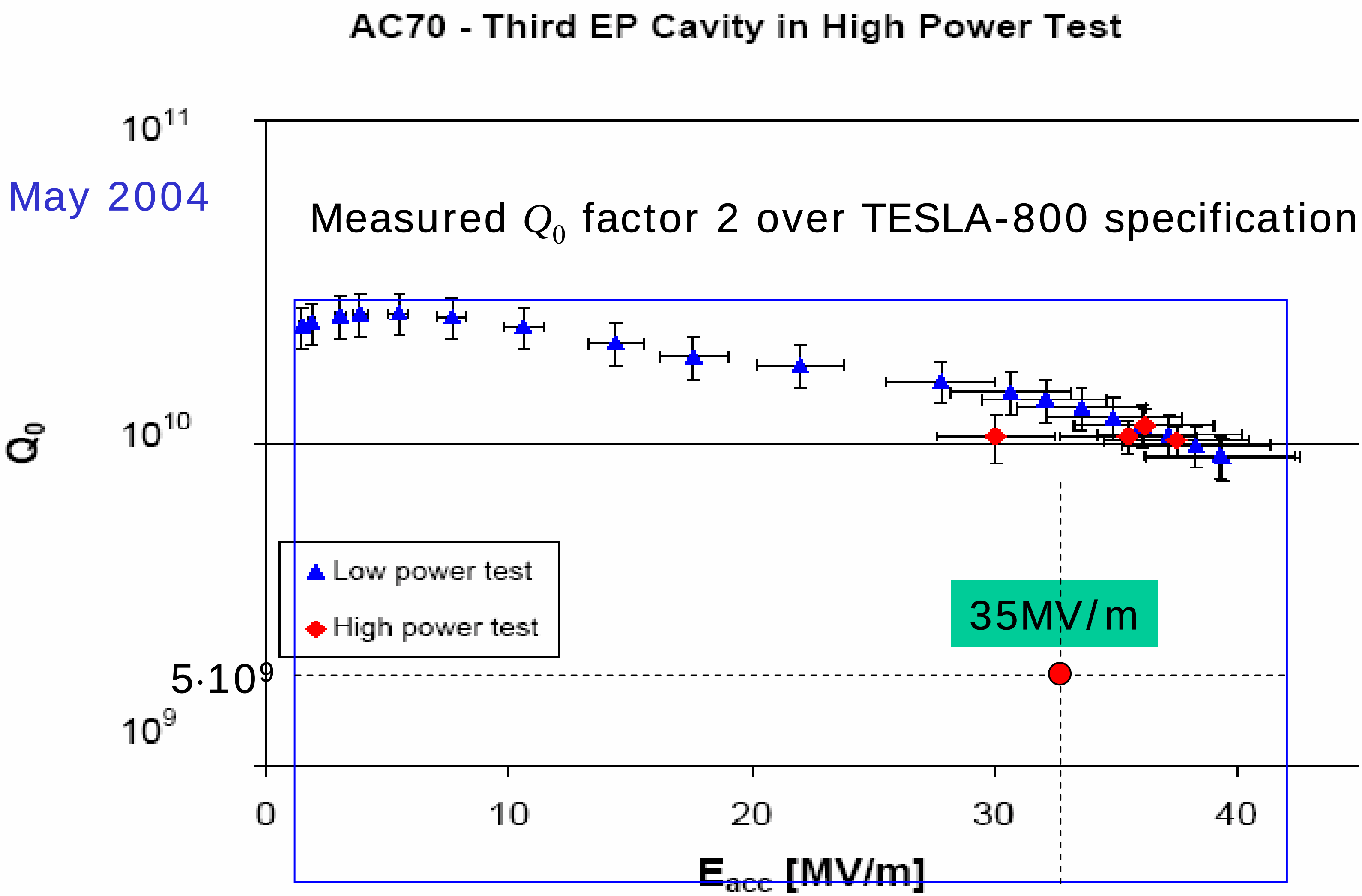
AC72
Low power test
High power pulsed test 1Hz
High power pulsed test 5Hz
Q_0
10^{11}
10^{10}
10^{9}
0
5
10
15
20
25
30
35
40
E_{acc} [MV/m]

35 MV/m



Q0
AC73
Acceptance test
System test, pulsed 5 Hz
System test, pulsed 10 Hz
System test, pulsed 10 Hz
E_acc [MV/m]

37 MV/m

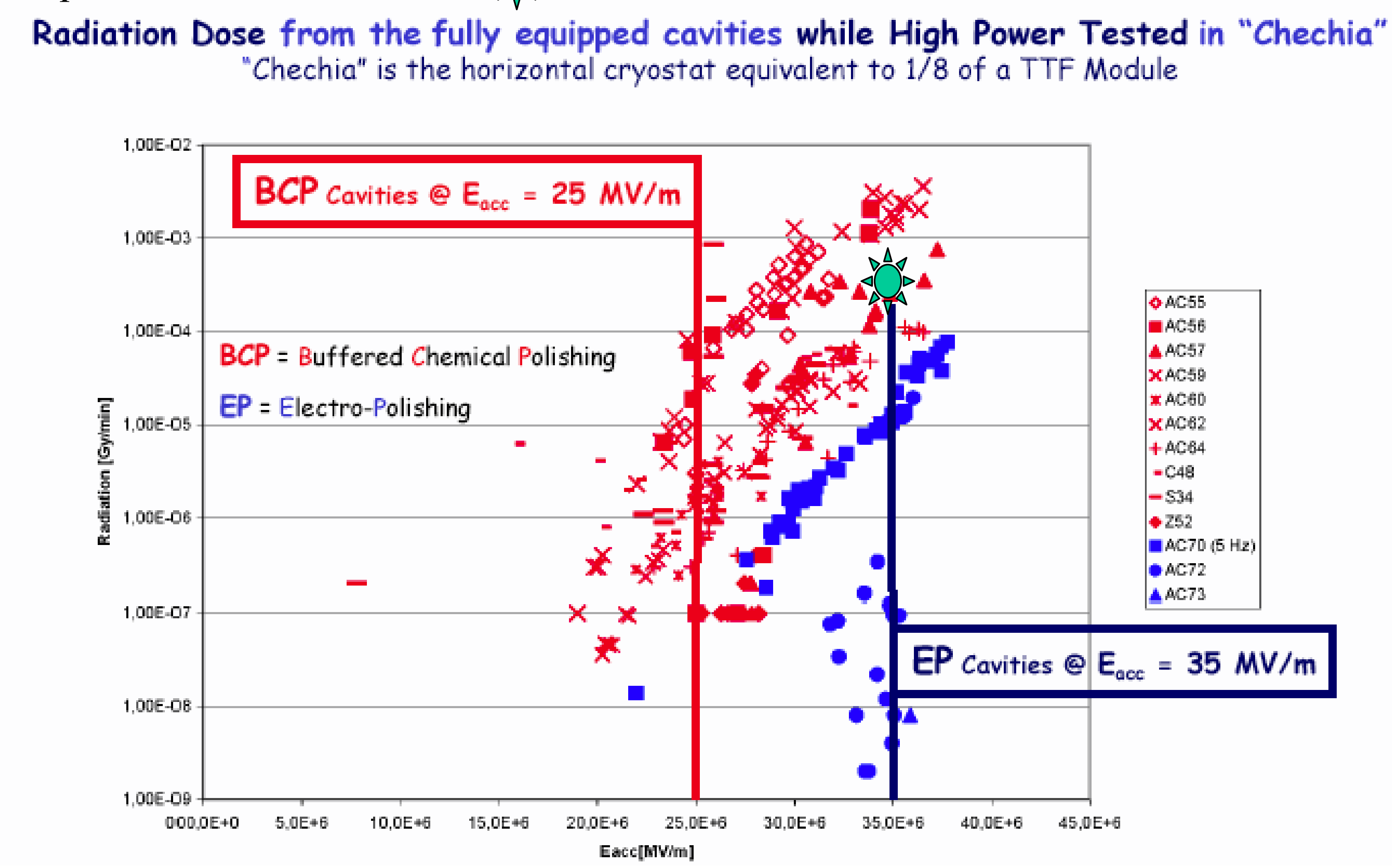


AC70 - Third EP Cavity in High Power Test
May 2004
Measured Q_0 factor 2 over TESLA-800 specification
10^{11}
10^{10}
$5\cdot10^9$
10^9
Q_0
Low power test
High power test
35MV/m
0
10
20
30
40
E_{acc} [MV/m]

Eacc = 38 MV/m

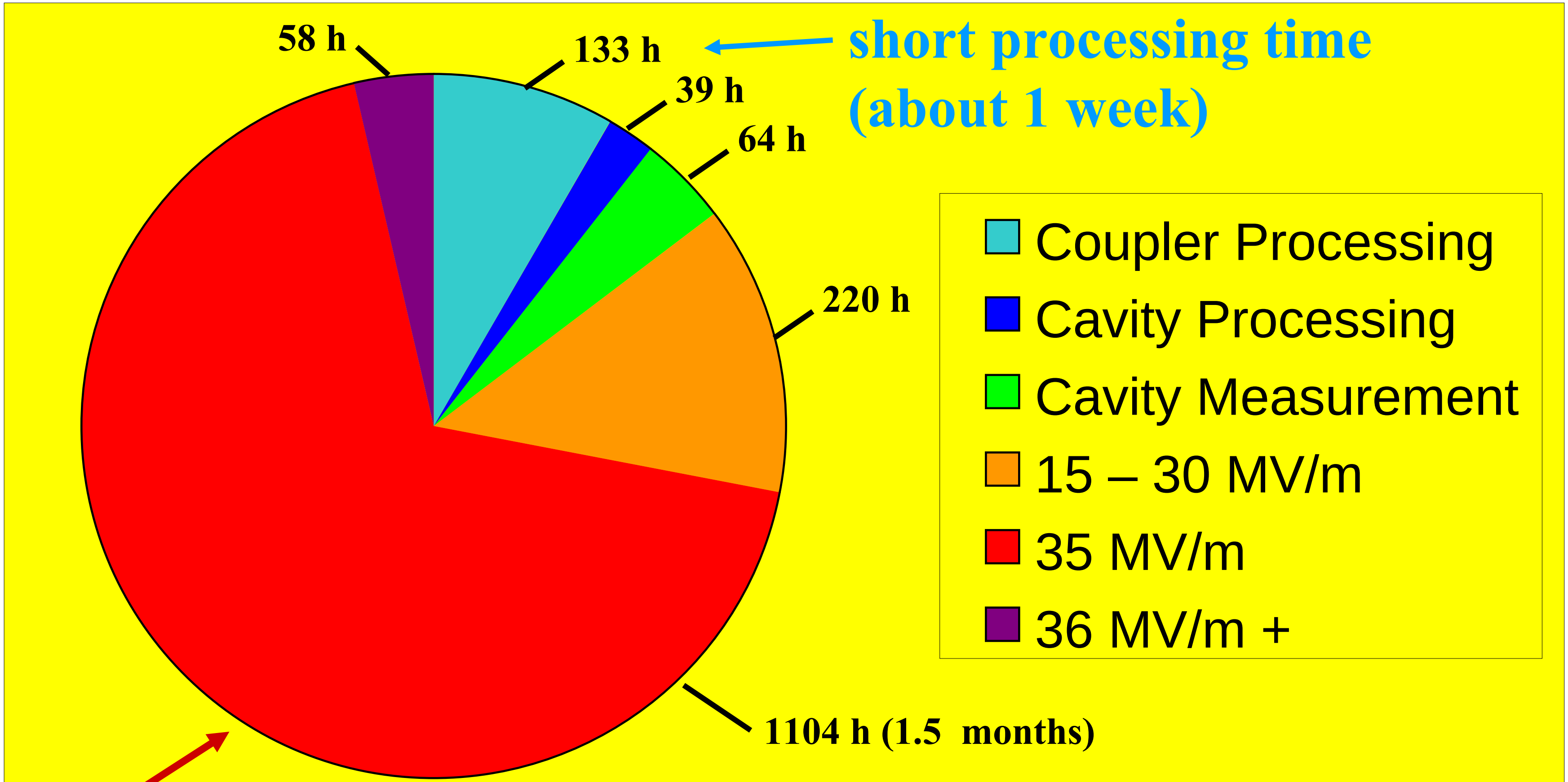
Again, electropolished cavities at 35 MV/m show less radiation than BCP cavities at 25 MV/m.. Cleaner preparaton achieved

50 nA @ 35 MV/m per cavity acceptable ≈ 250 mW per cavity at 35 MV/m, estimated acceptable radiation dose



Pulsed Long Term High Power Test

Time Distribution of RF Test:



Long term test: Cavity and input coupler did not cause a single trip event!

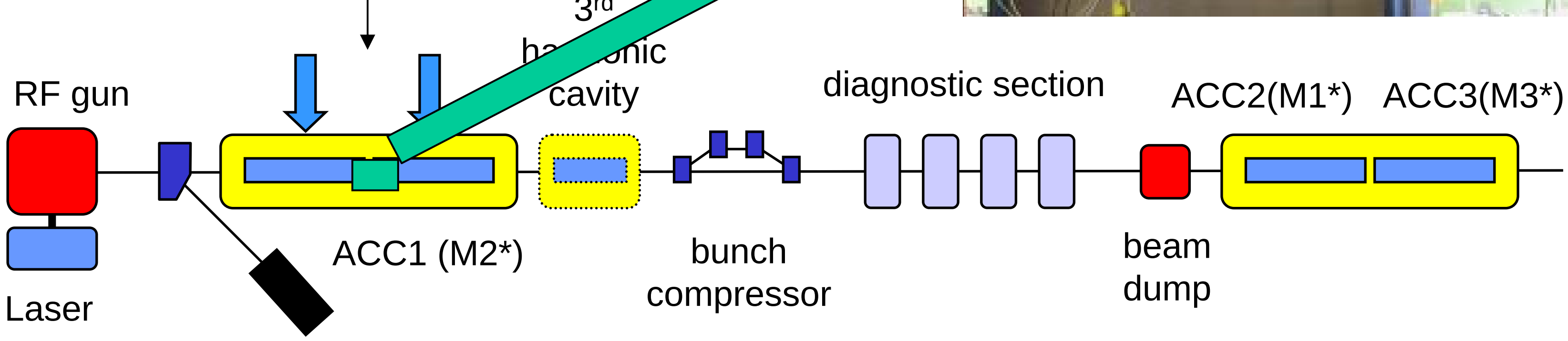
35MV/m in a complete Cryomodule

AC72: one of **five** high-performance EP cavities

Transferred to single cavity module

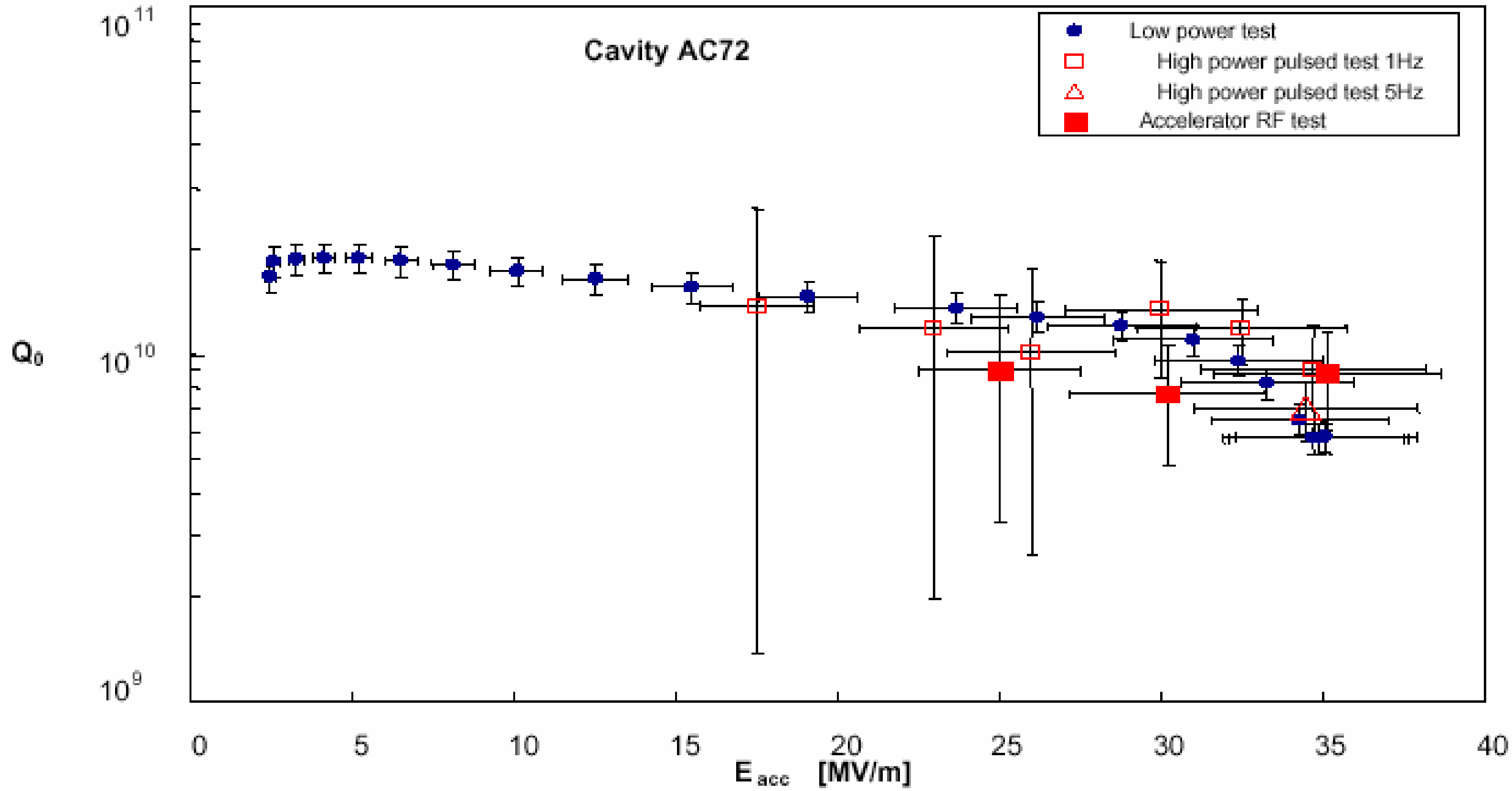
Full 1/8th CM horizontal test (CHECHIA)

Transferred to complete module

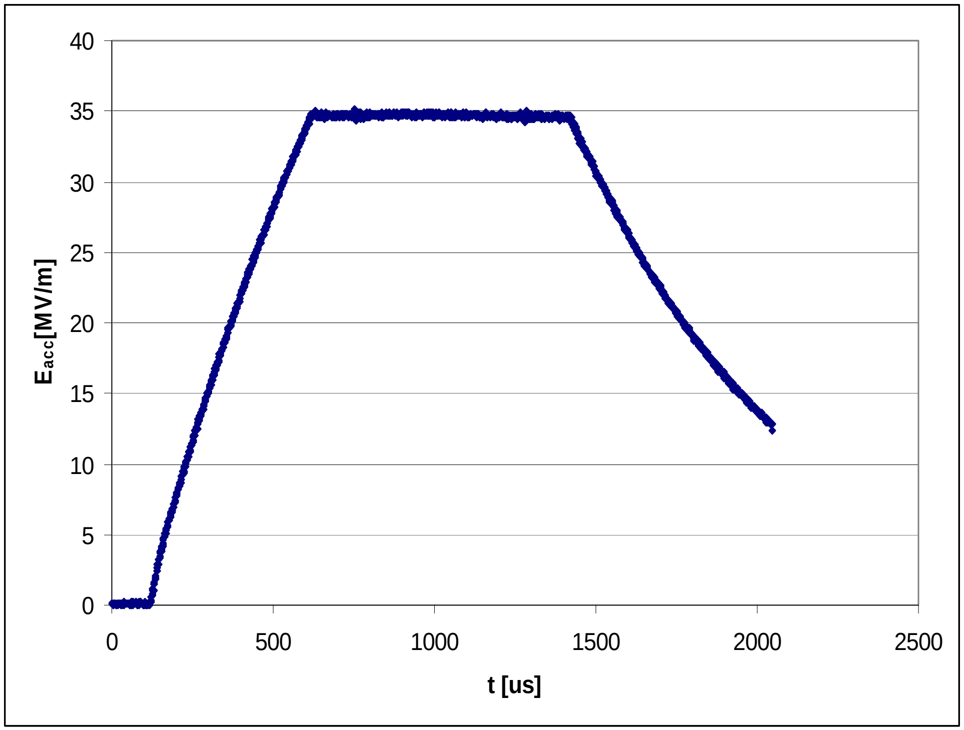


Cavity Test Inside a Module (ctd.)

- Testing has just begun
  - Standard X-ray radiation measurement indicates radiation-free up to 35 MV/m
  - LLRF has been operational at 30 MV/m
  - Active compensation of Lorentz-force detuning tested



The 35MV/m Cryomodule Test



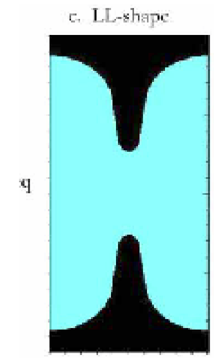
RF pulse with feedback in cavity 5 (AC72) during beam acceleration

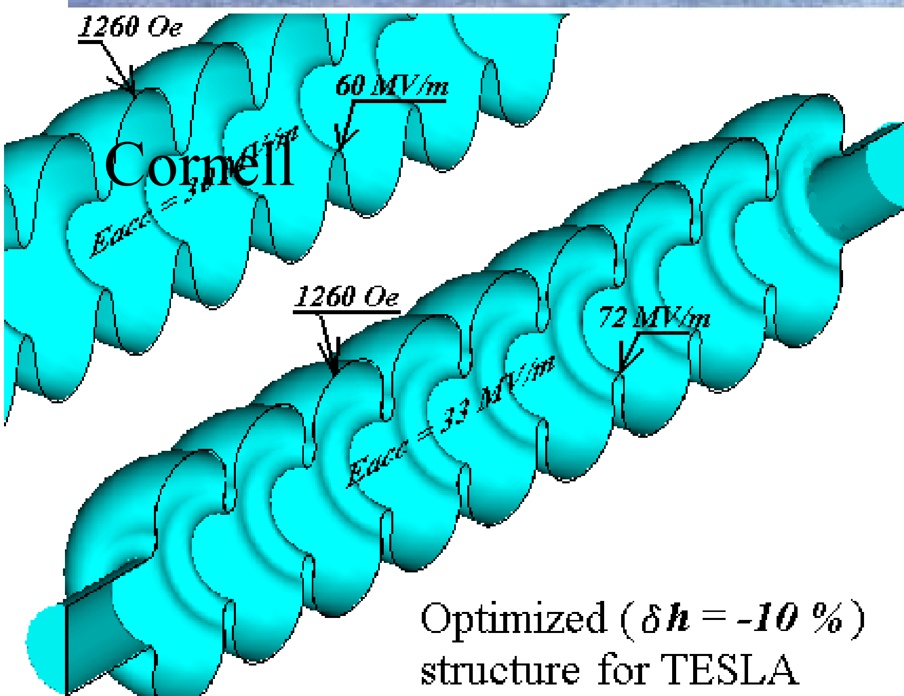
- RF measurements showed no degradation of performance (35MV/m achieved)
- RF gradient measurement calibrated using beam (energy spectrometer)
- No measurable radiation detected
(no dark current)

35 MV/m EP TESLA Cavity accelerates beam for the first time ☺

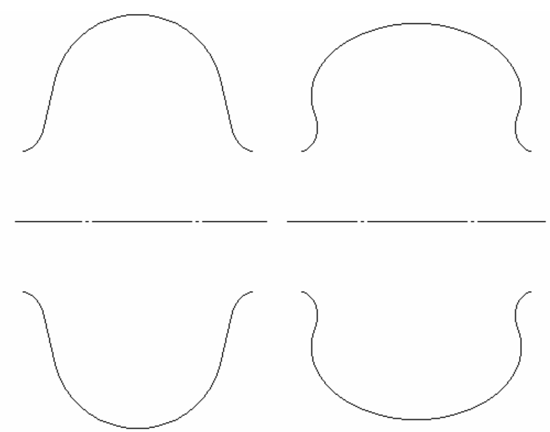
Advanced R&D News:
Can We Improve the TESLA Geometry?

Jlab



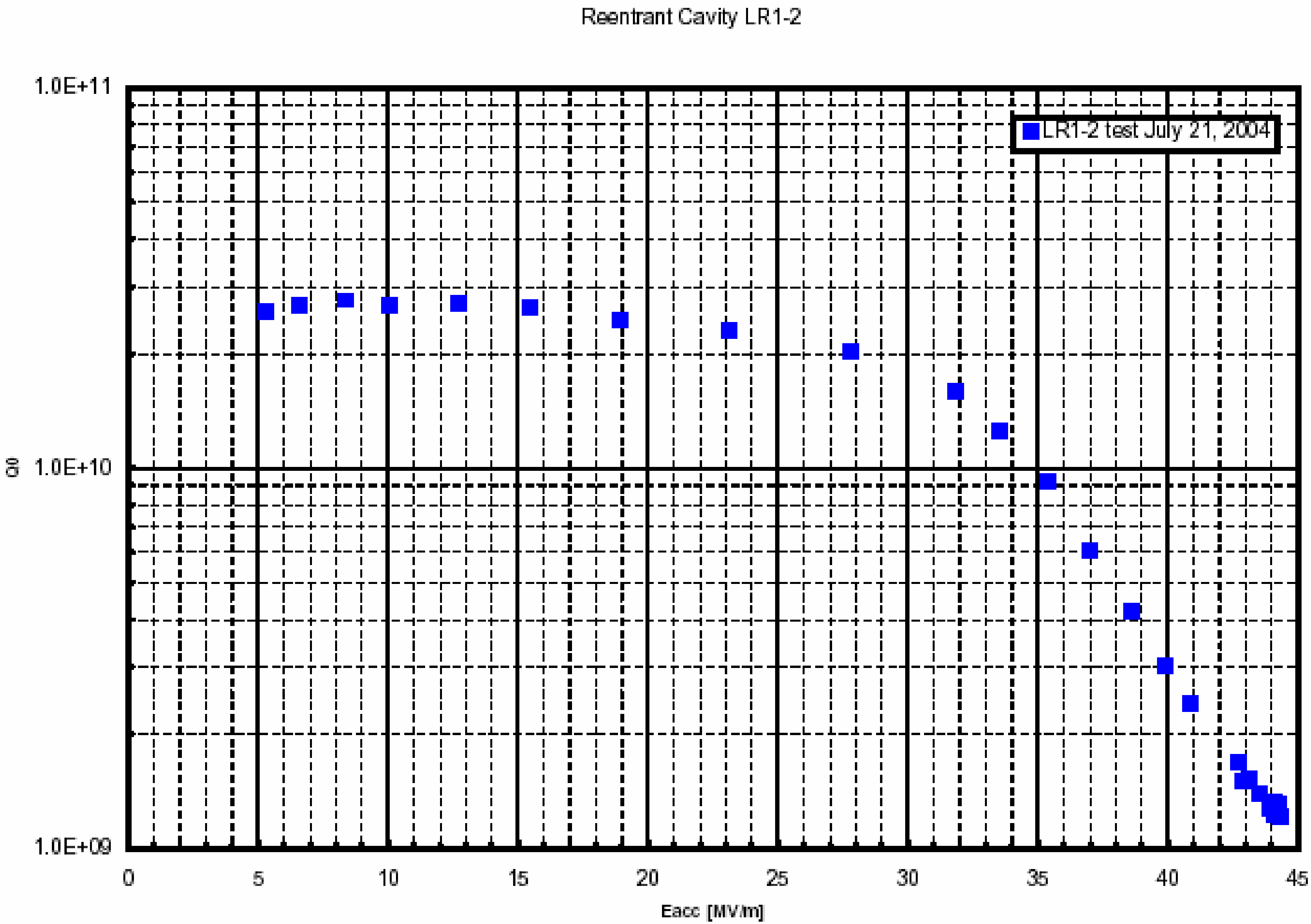


Optimized (δh = -10 %)
structure for TESLA



Re-entrant

New ideas always proved out with single cells first



Eacc ≈ 44 MV/m

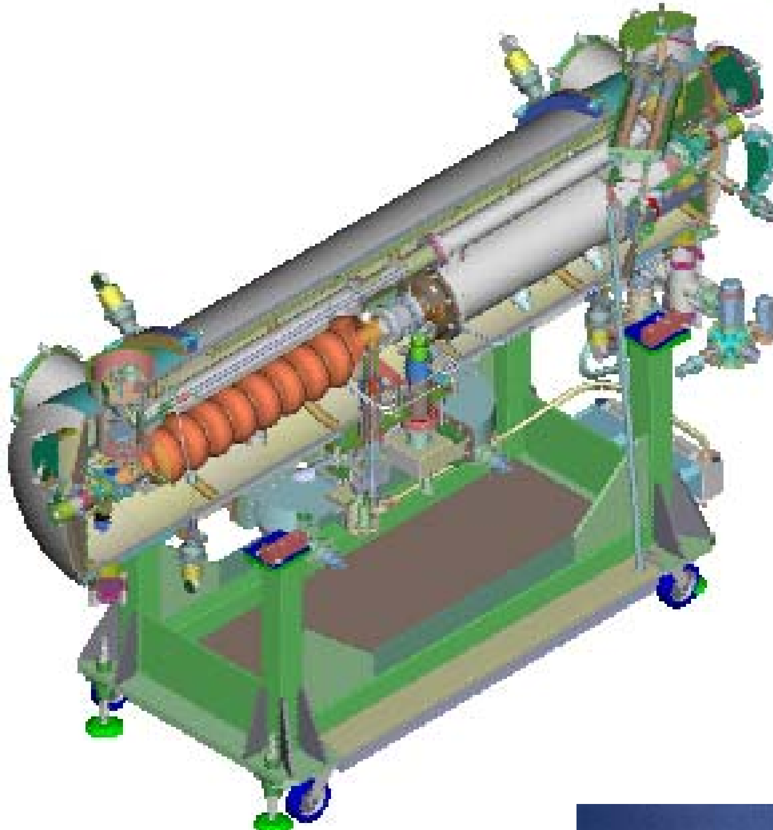
44 MV/m needed for one TeV

Cold Technology Industrialization Headstart

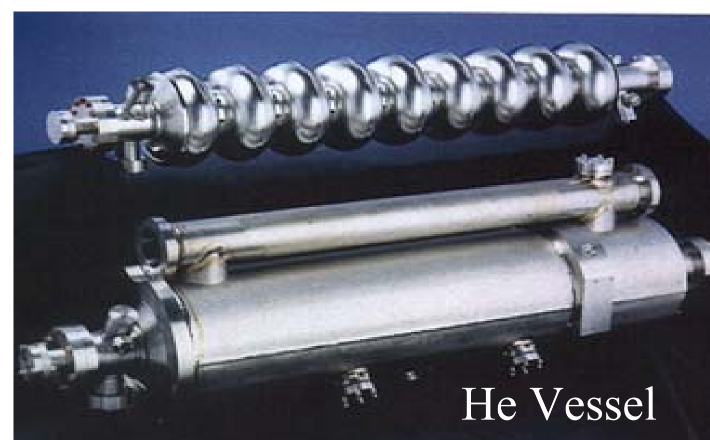
- 110 cavities produced by ACCEL, CERCA and ZANON.
- 10 cryomodules components produced by ZANON, assembled at DESY with help of ZANON
- Nearly 100 couplers produced at industry: ACCEL and CPI
- 10 MW Klystrons from Thales
- CPI and Toshiba klystrons on the way
- 7 Modulator systems by PPT/DESY

ACCEL

High Pressure Rinsing



Twin cryomodule for Rossendorf and Daresbury



10 cryomodules parts produced/ assembled at DESY..

E. ZANON S.p.A.

Integrated cold time = 10 cryomodule-years

Cavities

9 cells SC cavity

7 cells SC cavity for the Superstructure

AREVA
CERCA

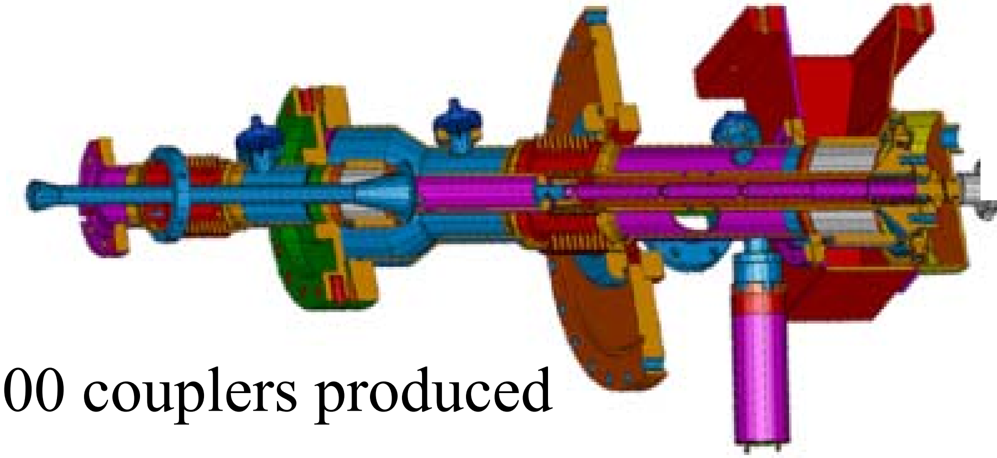
Cavities for TTF

Cryomodule Experience from LEP Production

CPI
Communications & Power Industries
beverly microwave division

&

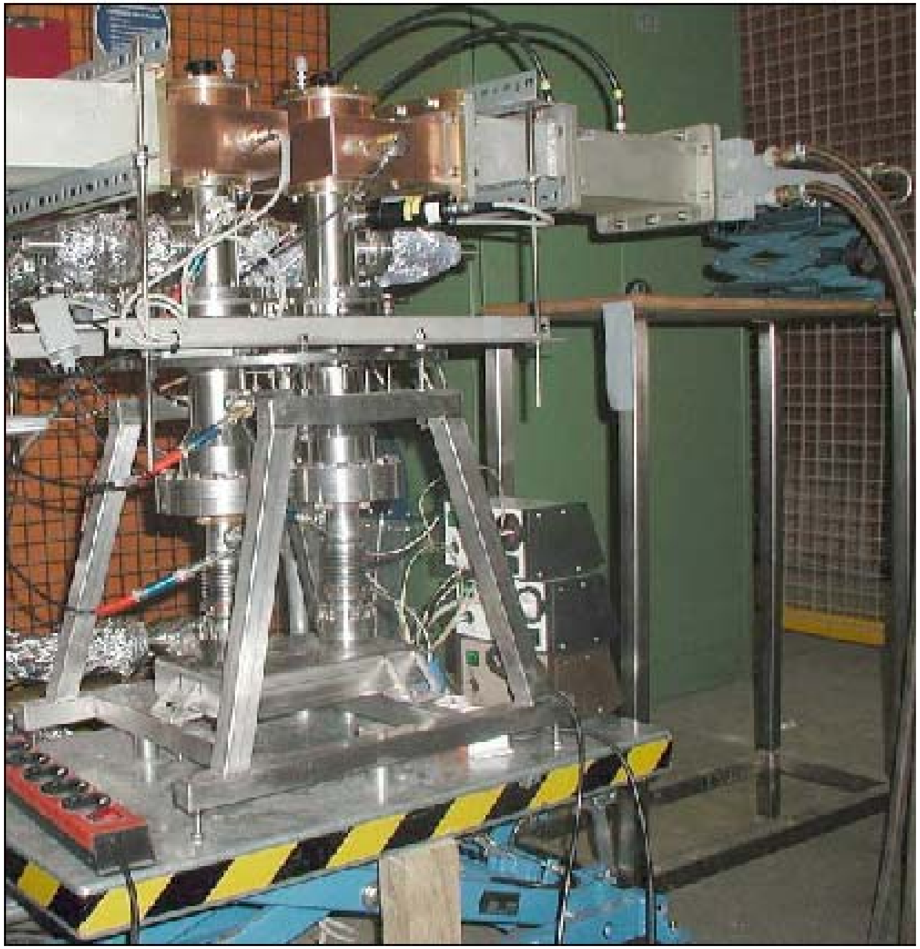
ACCEL

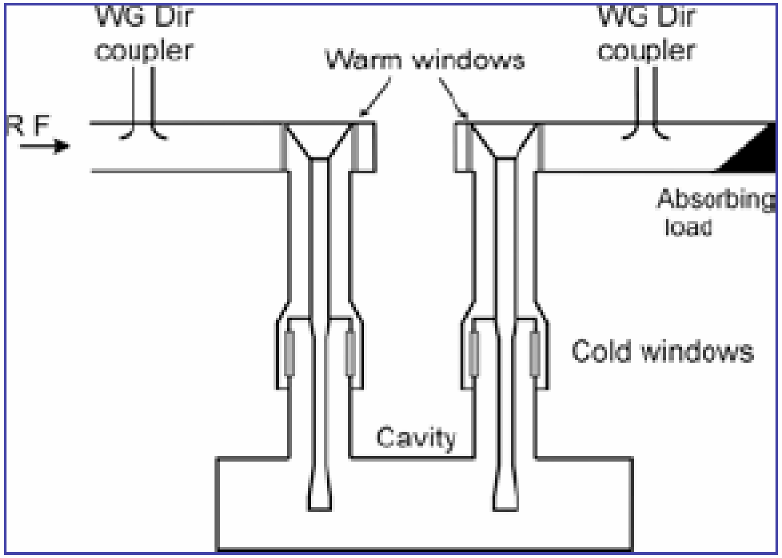


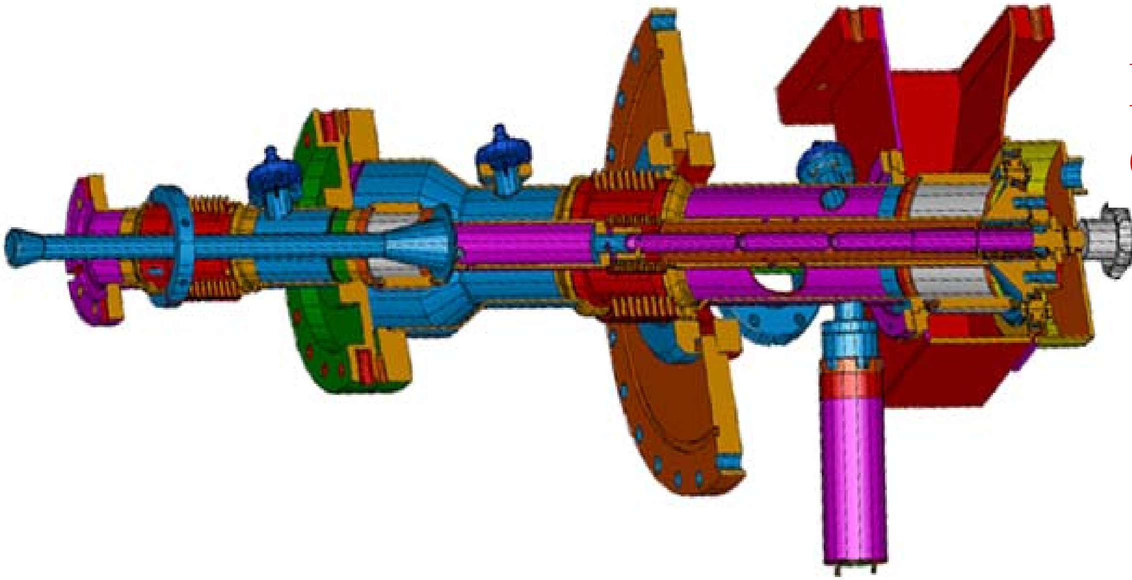
Input Coupler

≈ 100 couplers produced

High Power Coupler Test Stand > 1 MW







Input Coupler

25,000 coupler-hours tests for style III

100,000 coupler-hours for style II

Requirements

	TESLA 9cell / upgrade
Peak power + control margin	250 kW / 500 kW
Repetition rate	5 Hz
Average power	3.2 kW / 6.4 kW
Coupling (Qext)	fixed ($3*10^6$)

Coupler Tests with Cavities

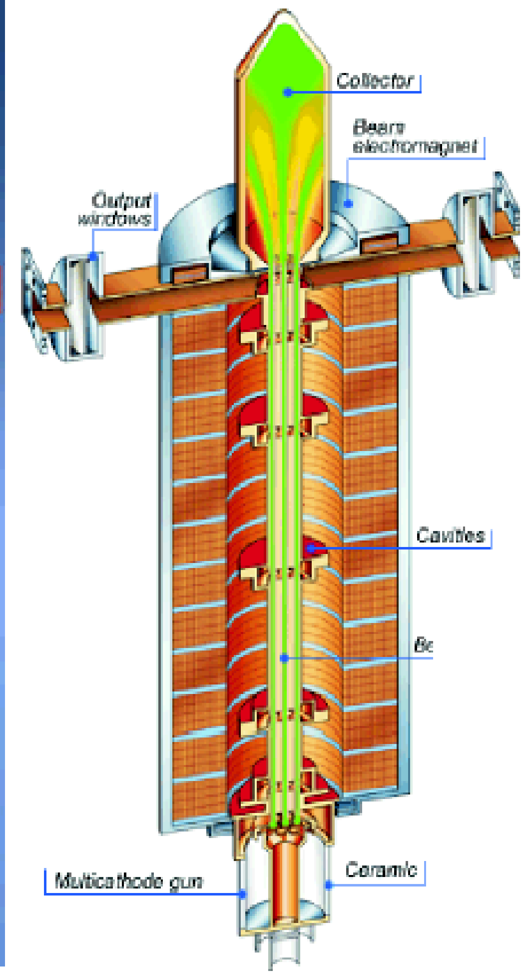
hiigh power test with Cavity	2Hz / <500µs	1MW
	5Hz/ 1.3ms SW	600 kW
	10Hz / 1.3ms	35MV/m
	cold test done	yes
fabricated total		62
assembled to		Mod.5, 6 (7, 8) SS
operated		2001-2004

THALES

–**First producer of prototype achieving specs.**

–**2 additional ‘production’ models**

–**Tests of modified tubes in July.**



TH1801
Multi-Beam
Klystron

CPI
Communications & Power Industries
microwave power products division

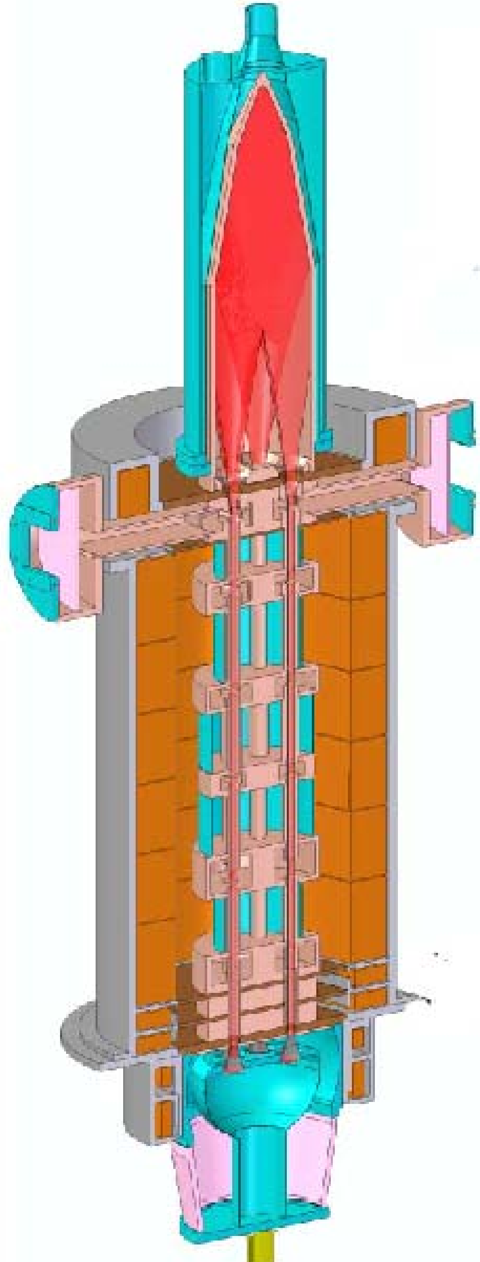
Photo gallery of the VKL-8301 MBK

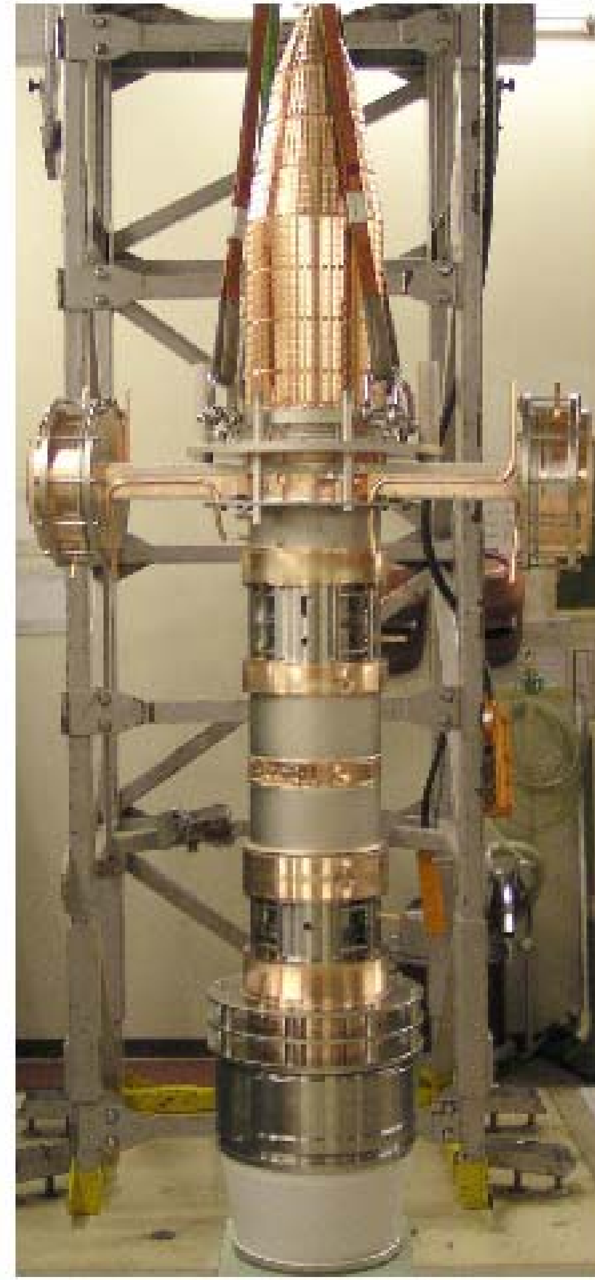
- –1st prototype development
- –**Achieved 10MW** for short pulse (tens of μs, h=60%)
- –Problems with longer pulse (understood and being addressed)

TOSHIBA

–First prototype being prepared for initial testing (July)

Figure 8 : The electron gun

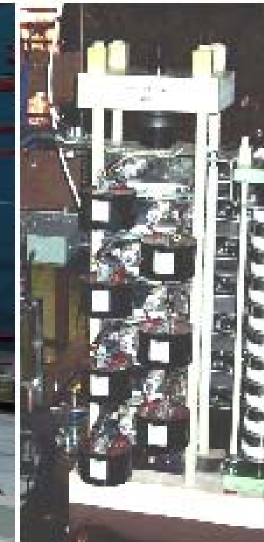




10 Modulators manufactured (3 FNAL, 7 DESY/PPT),

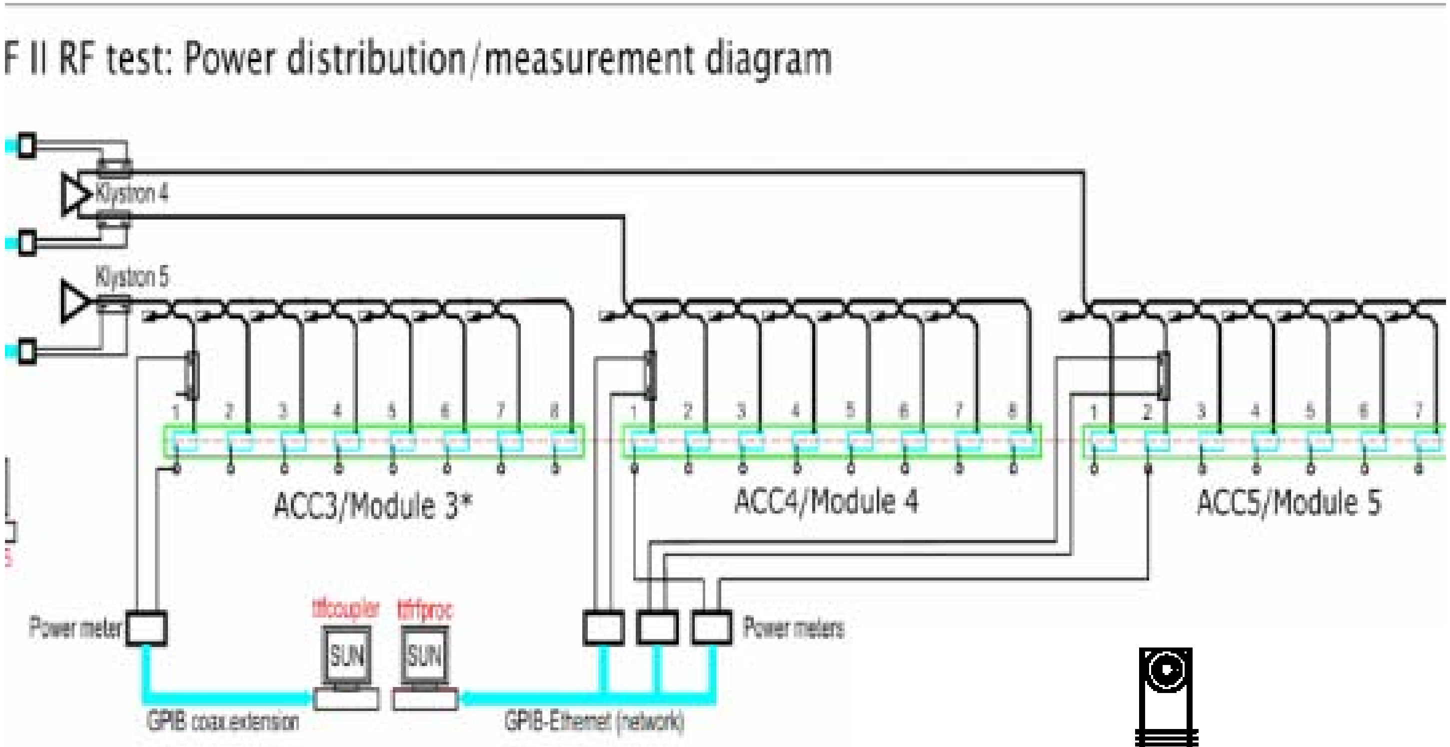
Of these are 7 in operation.

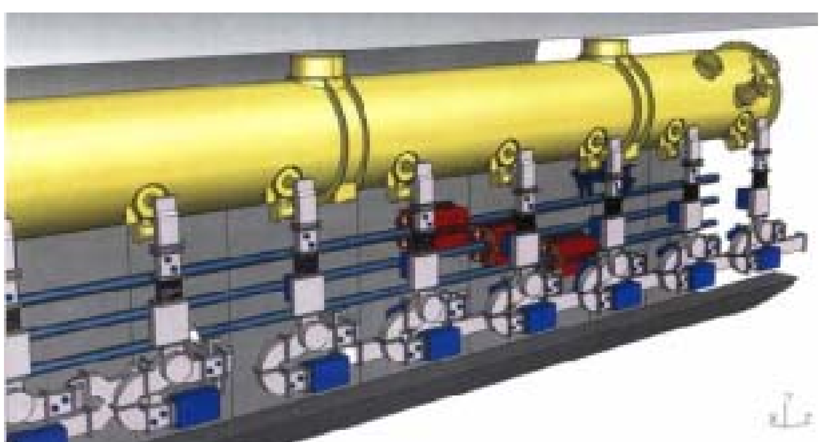
#1 is in use at TTF since 10 years.

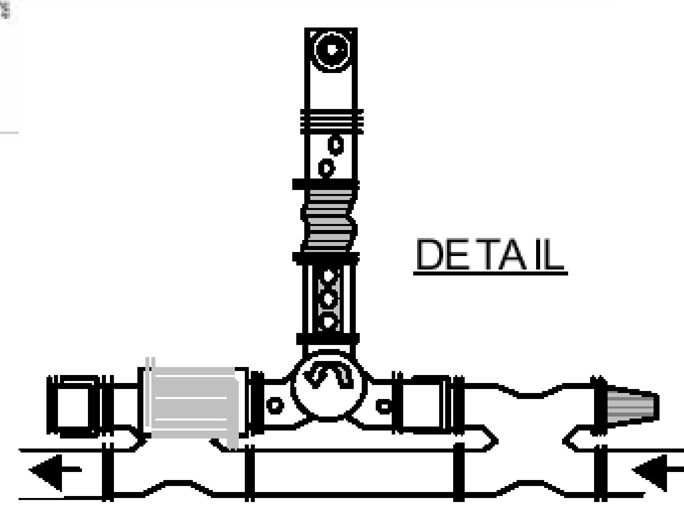


IGCT Stack

RF Systems Assembled and Tested in TTF







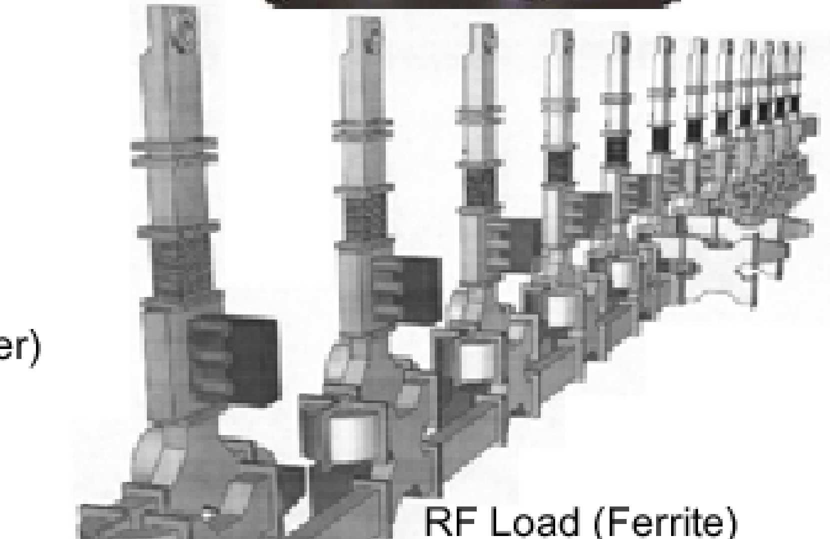
Standard Catalog Items

RF Waveguide Components

3 Stub Tuner (IHEP, Bejing, China)

E and H Bends (Spinner)

Circulator (Ferrite)



Hybrid Coupler (RFT, Spinner)

RF Load (Ferrite)

RF Load (Ferrite)

Momentum of Cold Technology

- 20 GeV XFEL ⟷ Cold LC
- Impact of TESLA technology on accelerators world-wide has important synergies with cold LC

European XFEL Project at DESY Will Be Important for a Cold LC

- 20 GeV => 1000 cavities and 125 cryomodules
- Major components such as klystrons, modulators… are the same as (or very similar to) those needed for a cold LC.
- DESY is preparing two major test facilities for cryomodules
  - Test for single prototype cryomodules
    - in operation end of 2005
  - X-FEL Module Test Facility
    - in operation 2008
- Other benefits of the XFEL project for cold LC
  - Accelerator design,
  - Large scale industrialization,
  - Operational aspects
    - controls, reliability, MPS, …
    - Expanding expertise of accelerator scientists, engineers, technicians...

Launched: Construction of XFEL Test Facility

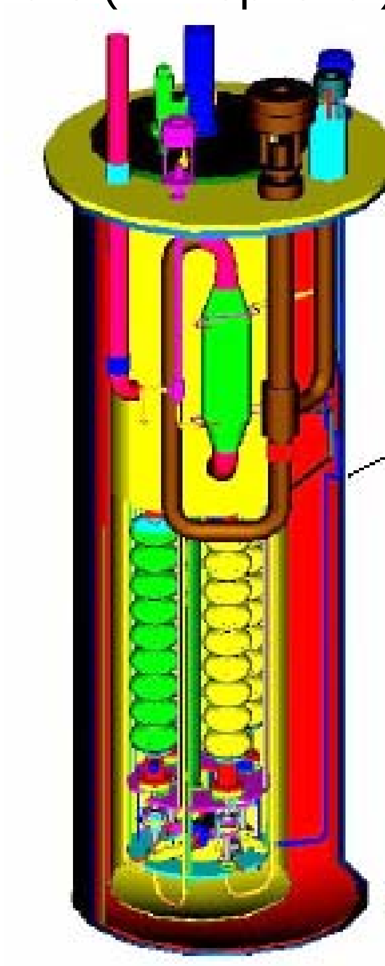
Vertical Test of 1000 X-FEL Cavities

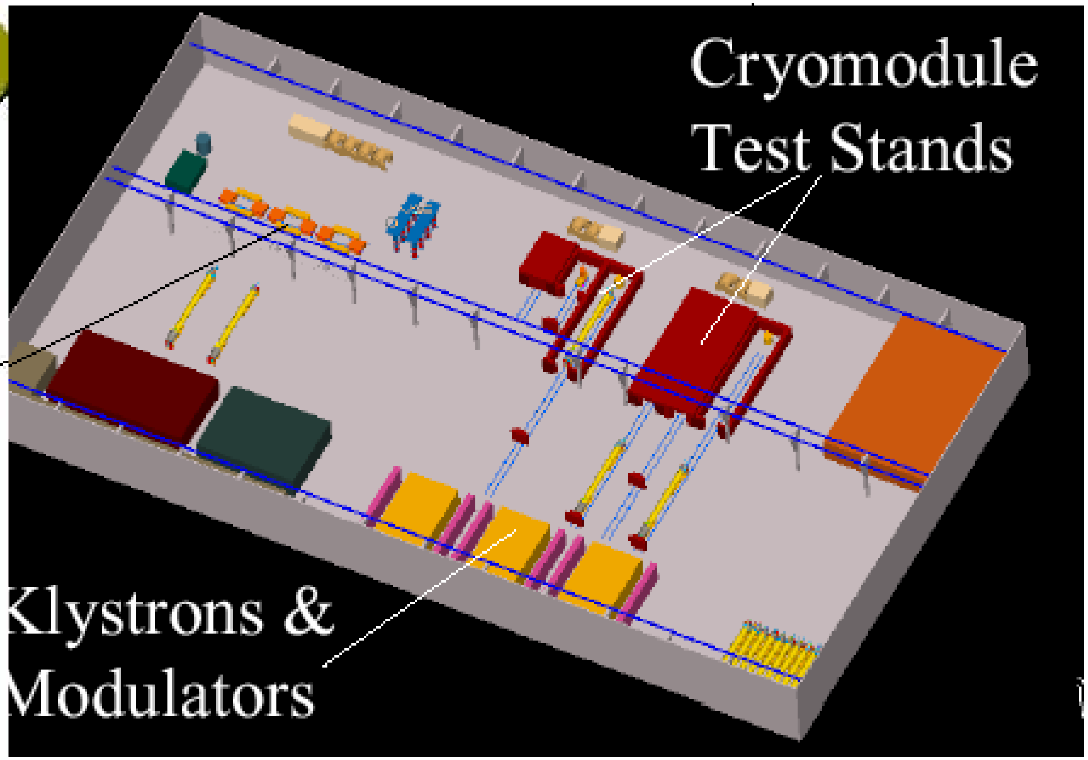
Production rate: 8 per week

-> two vertical dewars (+ 1 optional)

Horizontal tests optional
(2 cryostats)

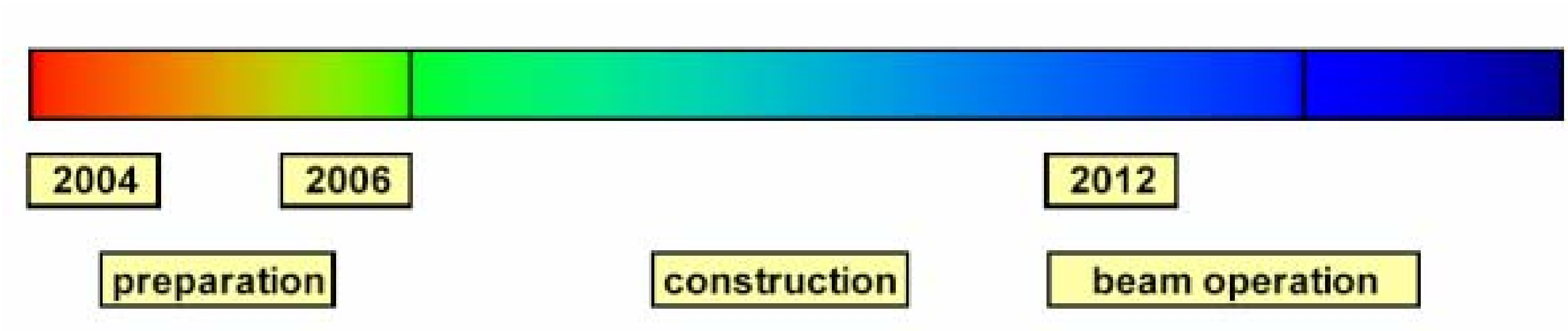
3 test stands
(+ 1optional)

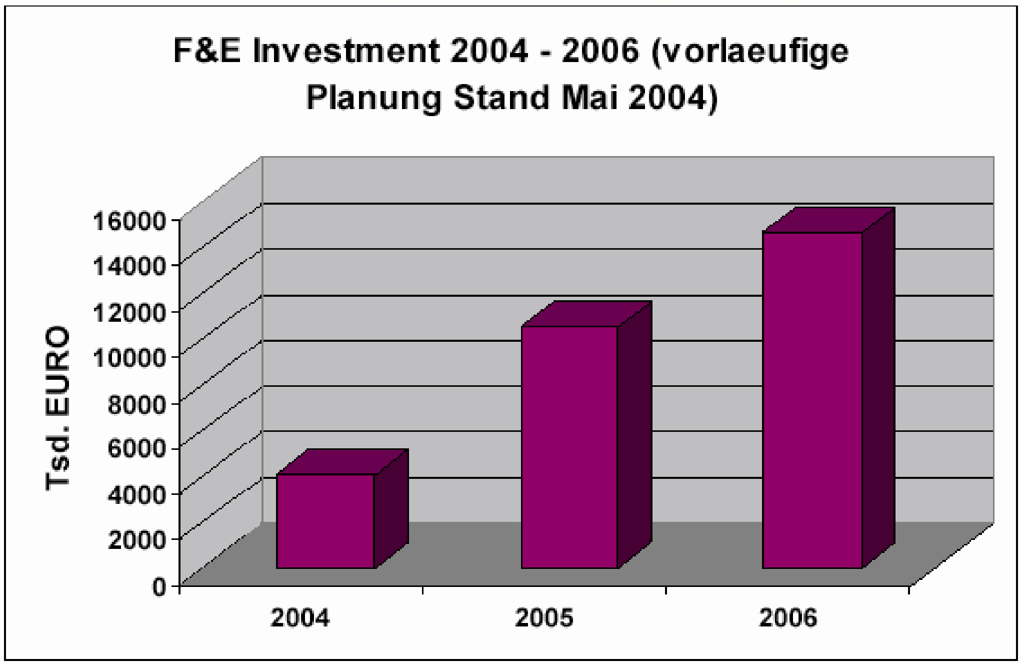




4 single cavities will be tested at the same time

German government Feb. 2003: go-ahead for XFEL as European project, incl. funding 50% of total 684 M€ (year 2000) project cost, + contribution from Länder HH & Schleswig-Holstein, ~ 40% European Partners





CARE (Coordinated Accelerator Research in Europe)

JRA SRF: High accelerating gradients, high quality factors, improvement of reliability, operating performance
and availability of the superconducting accelerating system , cost reduction of the SRF cavities and components

EU-Support: 5 Mio €

(2004 – 2008)

WORKPACKAGES

Improved Standard Cavity Fabrication
Seamless Cavity Production
Thin Film Cavity Production
Material Analysis
Surface Preparation
Cavity Tuners
Power Couplers
Cryostat Integration Tests
Low Level RF
Beam Diagnostics

Infrastructure: TTF

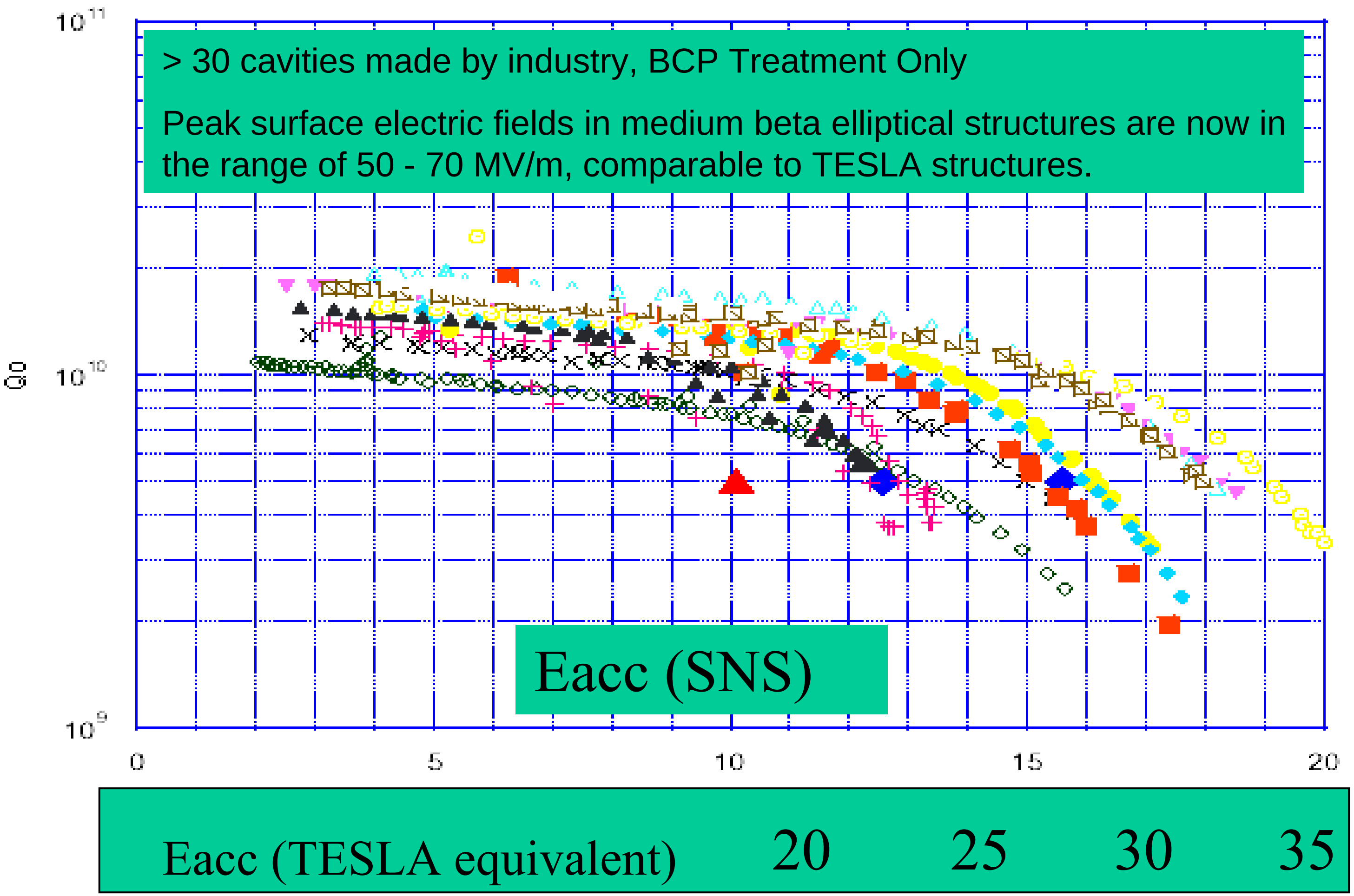
Gradient Progress for TESLA and TTF Success Has Impacted World-Wide SC Accelerators

- SNS (Spallation Neutron Source) switched to SC in 2000
  - Adopting many aspects of TESLA technology

- SNS cavities reach comparable performance,
  - e.g. BCP cavities reach surface fields corresponding to 22 - 35 MV/m fields for TESLA shape cavities

.

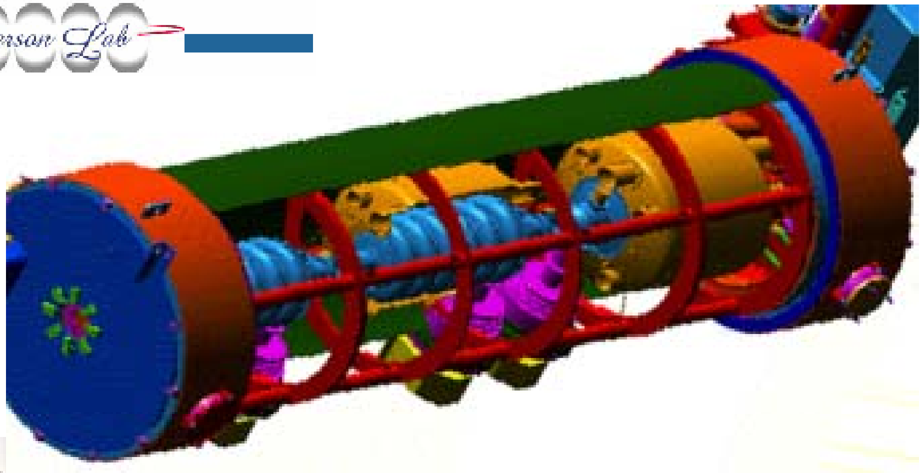
Performance of SNS Structures, JLAB



β = 0.61, 805 MHz,

Epk/Eacc = 3.5

SNS: First High Intensity Superconducting Proton Linac, Switched to SC in 2000



11 completed

6 cryomodules

installed at SNS

Momentum of Cold Technology Is Propelling New Accelerators World Wide

For nuclear physics, basic energy sciences (condensed matter and biophysics) basis: SRF linac technology.

1) The Rare Isotope Accelerator (RIA) (located at Argonne or MSU)

2) III.5 and IVth generation light sources at Cornell, JLAB, LBNL, MIT, Daresbury, BESSY, Saclay using SRF -Linac- based ERL or FEL…

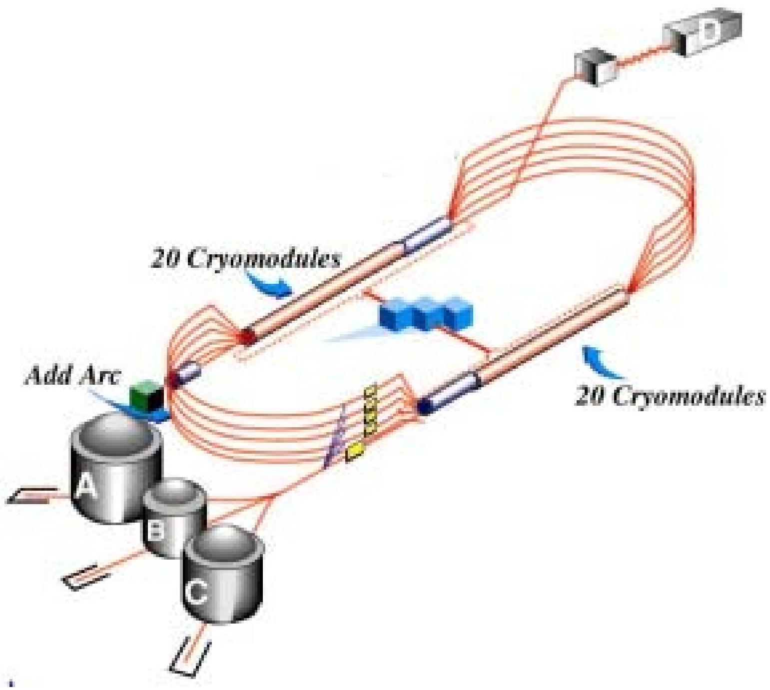
3) 12 GeV Upgrade to JLAB electron linac, extensions of FEL/ERL and the proposed ELIC (Electron Light Ion Collider).

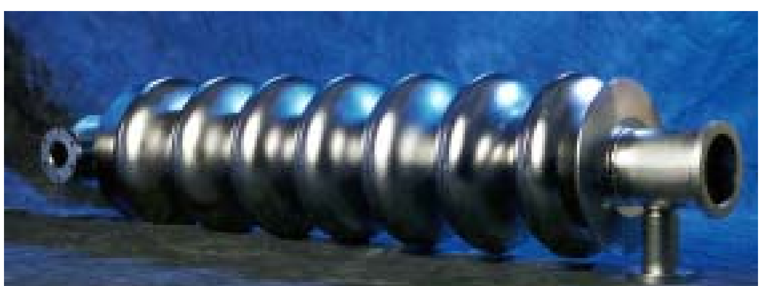
4) Brookhaven plans to use ERLs for electrons colliding with RHIC heavy ion beams (E-RHIC) and for electron cooling of the RHIC beams.

5) SNS upgrades to achieve higher beam power ~ 4 MW.

6) Proton driver at Fermilab and BNL, endorsed by Fermilab Long Range Planning Committee.

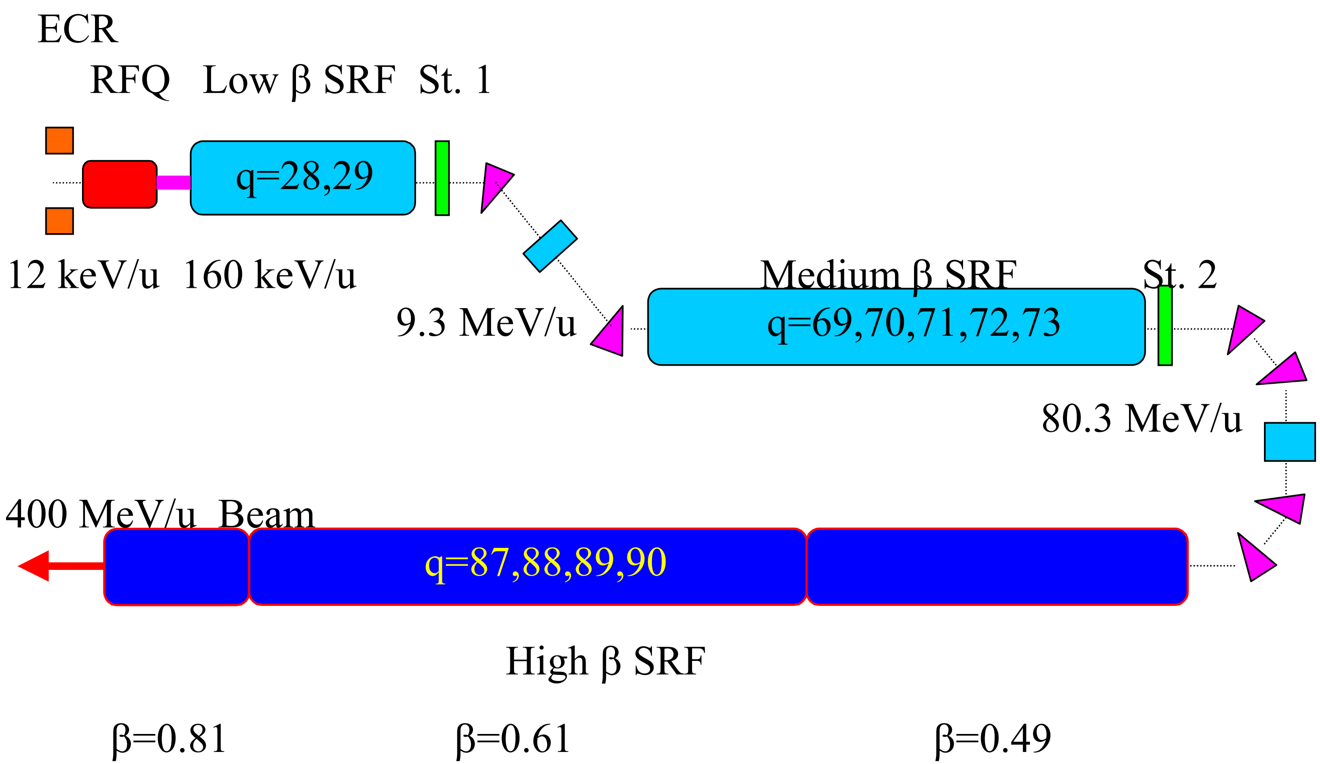
CEBAF 12 GeV Upgrade

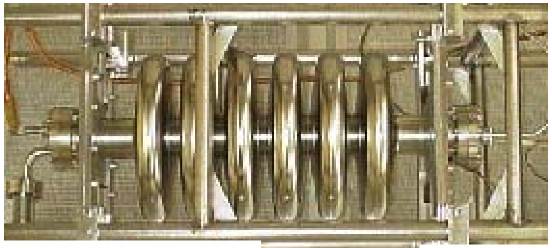




Rare Isotope Accelerator (RIA) for Nuclear Astrophysics
High Priority for Nuclear Physics

NSCL





SNS

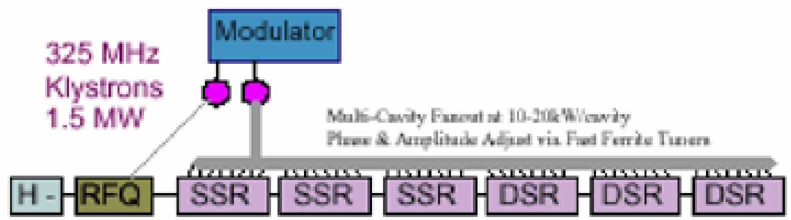
Jefferson Lab

MSU

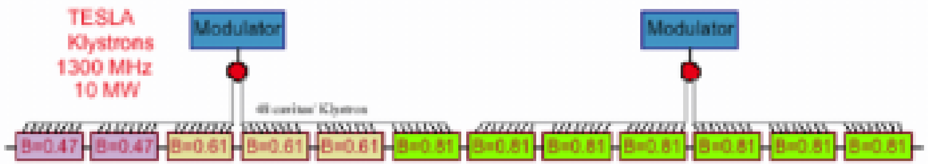
Fermilab Proton Driver

8 GeV SC Linac: Based on TESLA and RIA

8 GeV 0.5 MW LINAC
12 Klystrons (2 types)
11 Modulators 20 MW ea.
1 Warm Linac Load
54 Cryomodules
~550 Superconducting Cavities

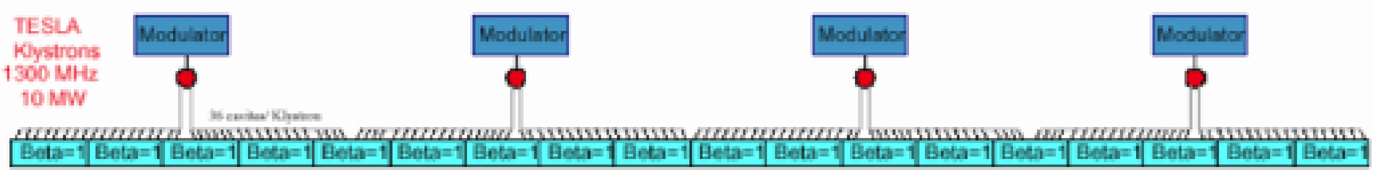


"Pulsed RIA"
SCRF Linac
325 MHz
0 - 120 MeV



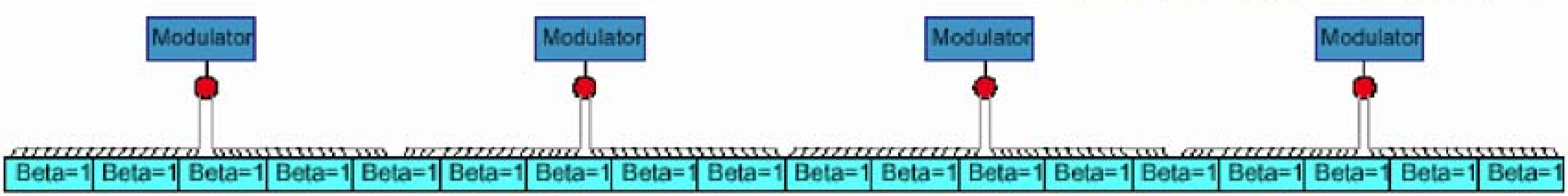
"Squeezed TESLA"
Superconducting Linac
1300 MHz 0.087 - 1.2 GeV

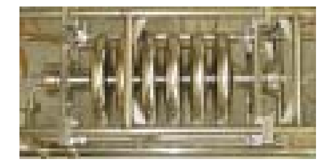
2 Klystrons
96 cavites in 12 Cryomodules

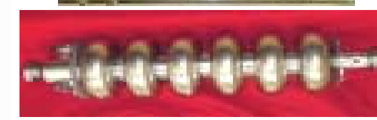


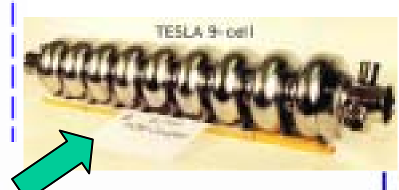
"TESLA" LINAC 1300 MHz Beta=1

8 Klystrons
288 cavites in 36 Cryomodules









Fermilab Proton Driver

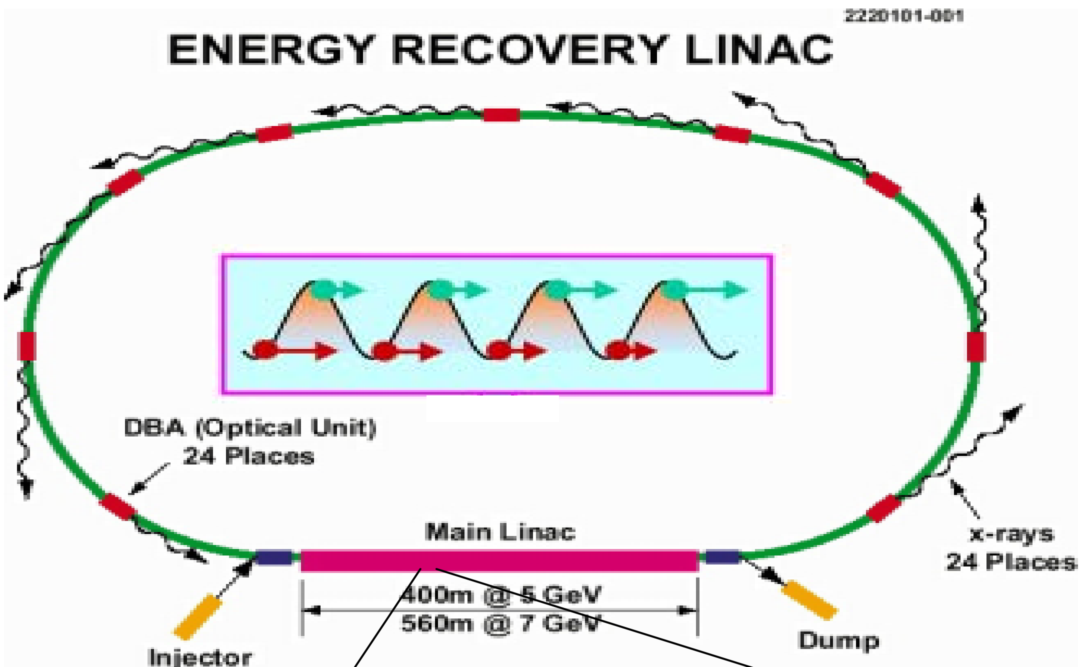
- Motivation
  - Neutrino "superbeams"
  - The Fermilab Linac and Booster are incapable of meeting the projected demand for protons ~10 years from now.

- High level parameters:
  - 0.5- 2.0 MW beam power at 8 GeV

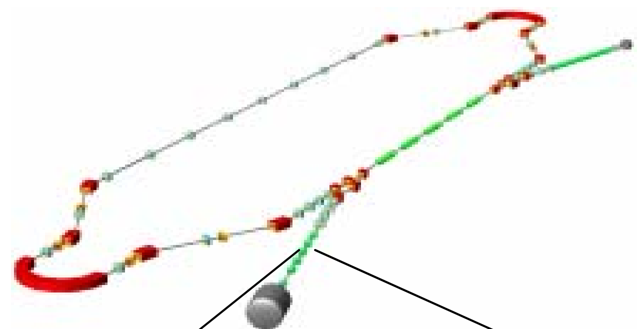
- TESLA frequency selected for 0.1 -> 1.2 GeV
- TESLA cavity selected for 1.2 - 8 GeV
  - 288 TESLA cavities in 36 cryomodules
  - Seed project for large scale industrial development

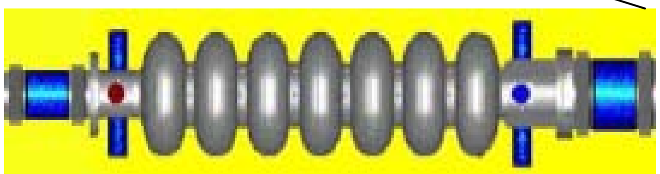
- Could serve as a ~1% system test required to promote industrialization and to insure reliability of the cost, schedule, and performance goals as part of a GDI sponsored systems test program.

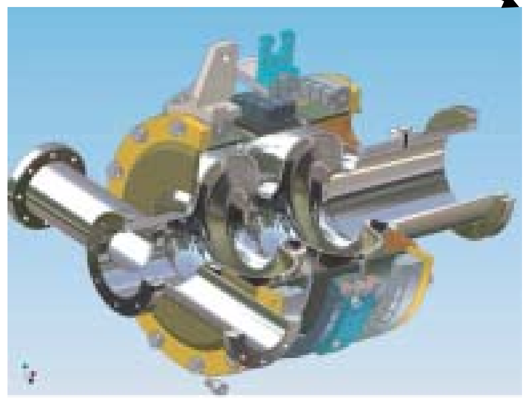
5 GeV Cornell - ERL

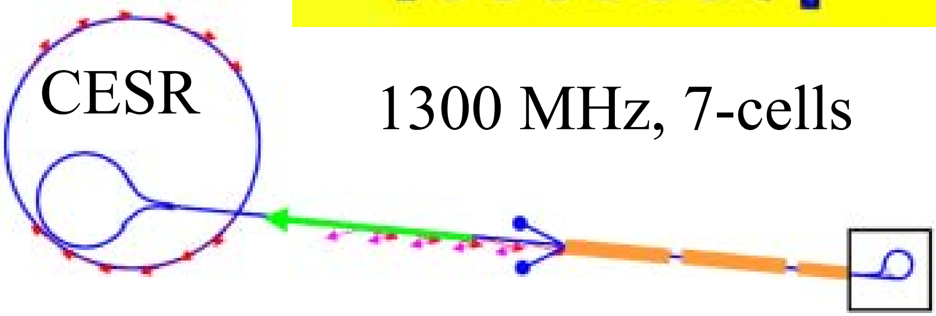


Prototype







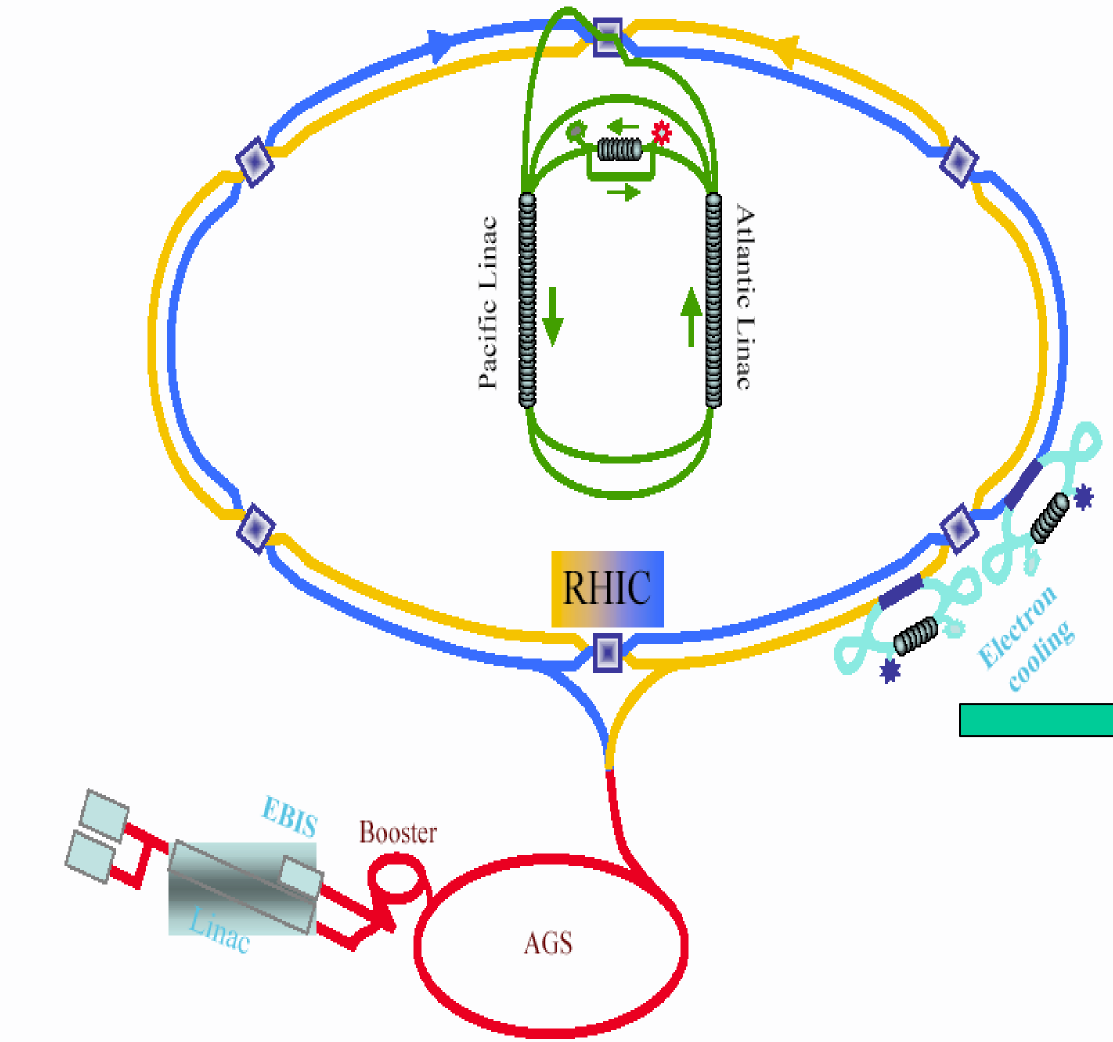


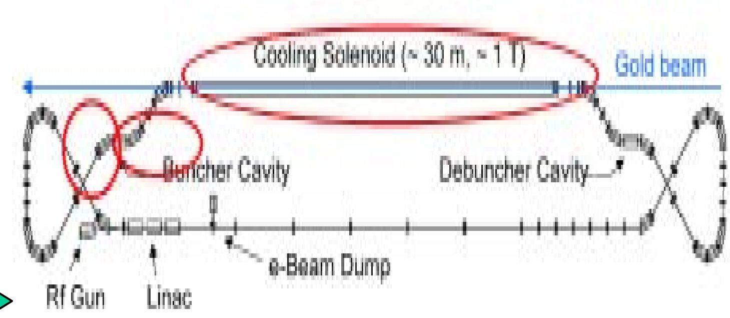
1300 MHz, 7-cells

BROOKHAVEN NATIONAL LABORATORY

RHIC

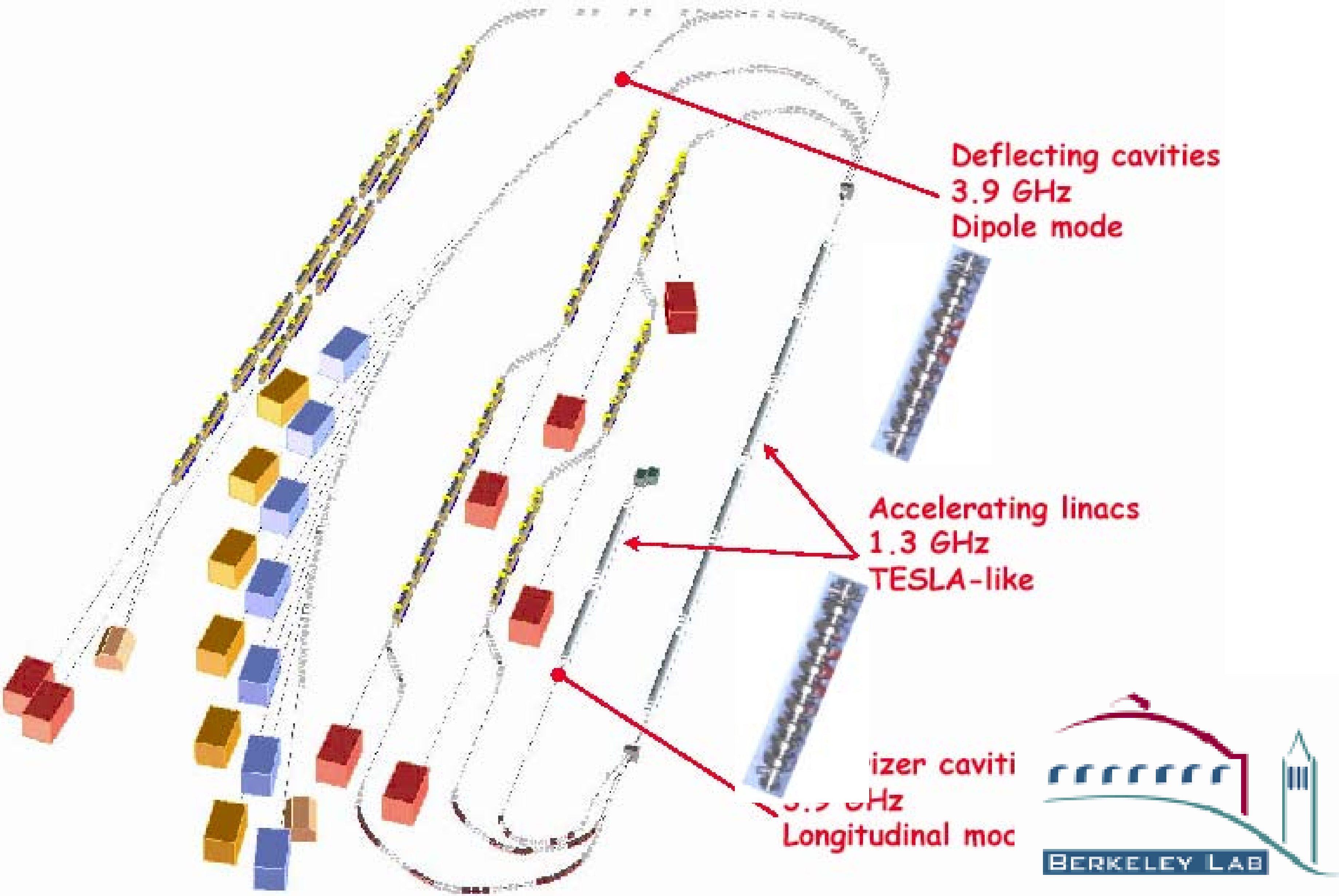
e-RHIC



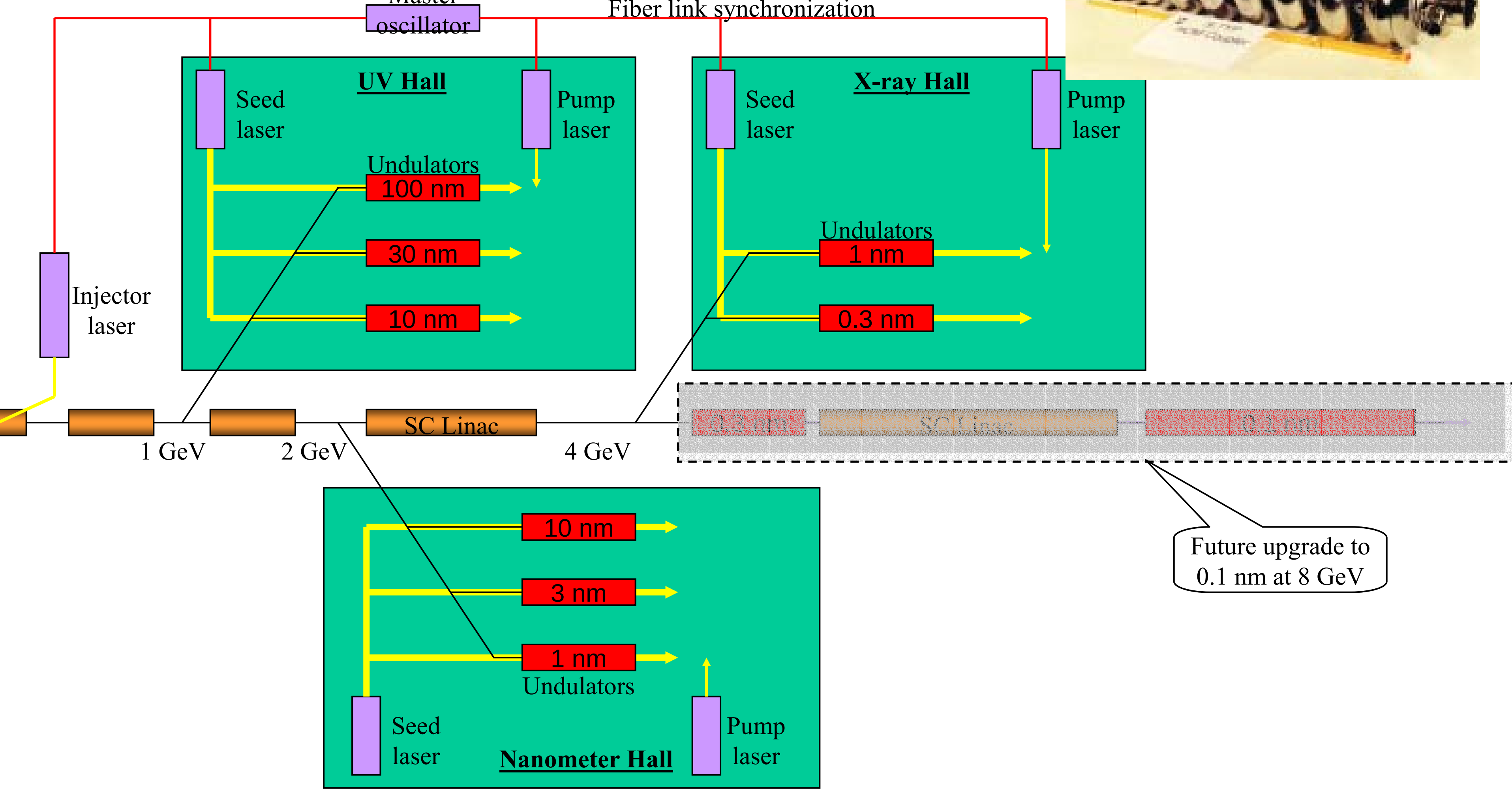


600 MeV ERL for cooling RHIC beam

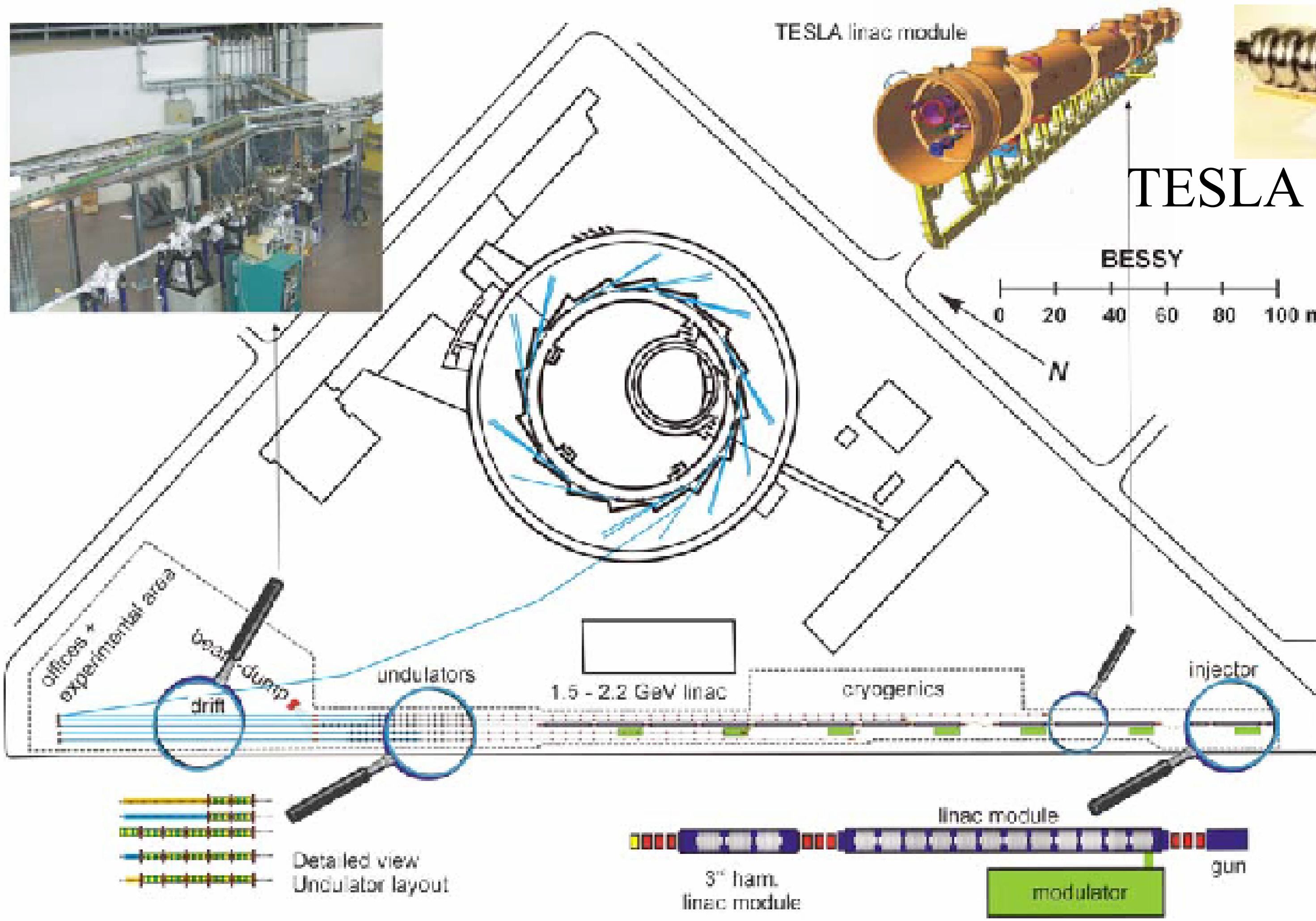
2.5 - 3 GeV LUX Linac-Based UltraFast Xray Facility



X-ray Facility at MIT



1 - 4….8 GeV



TESLA Cryomodule

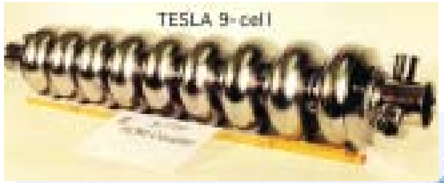
1.5 - 2.2 GeV

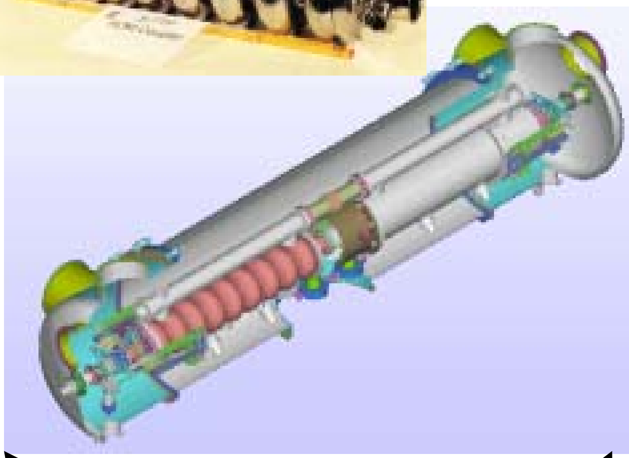
BESSY

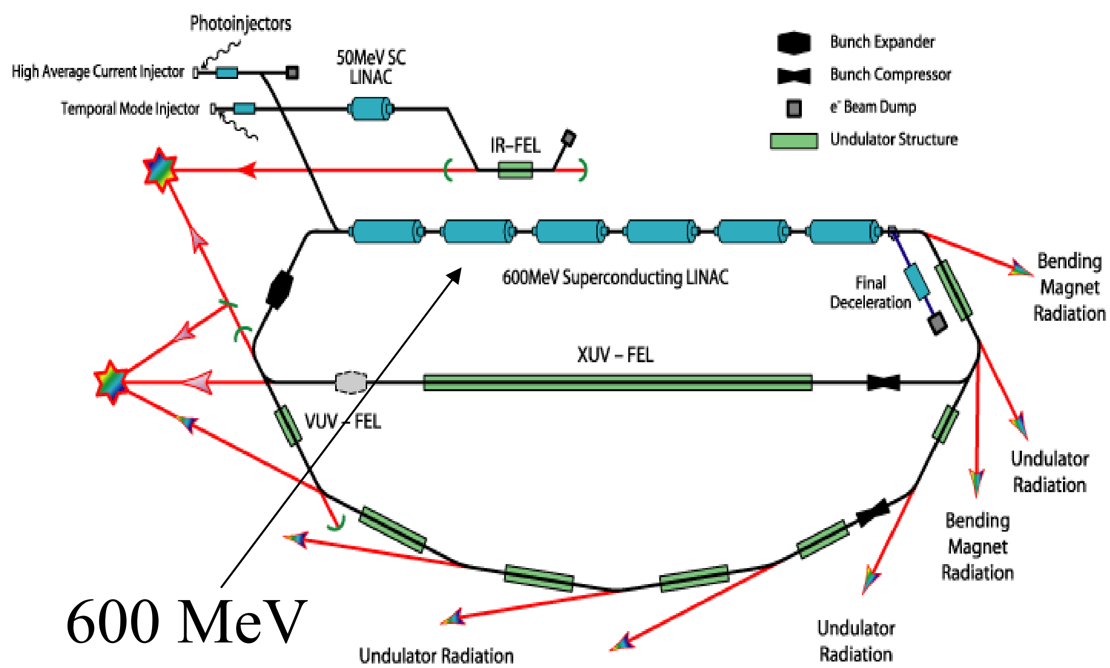
4GLS DARESBURY

Daresbury

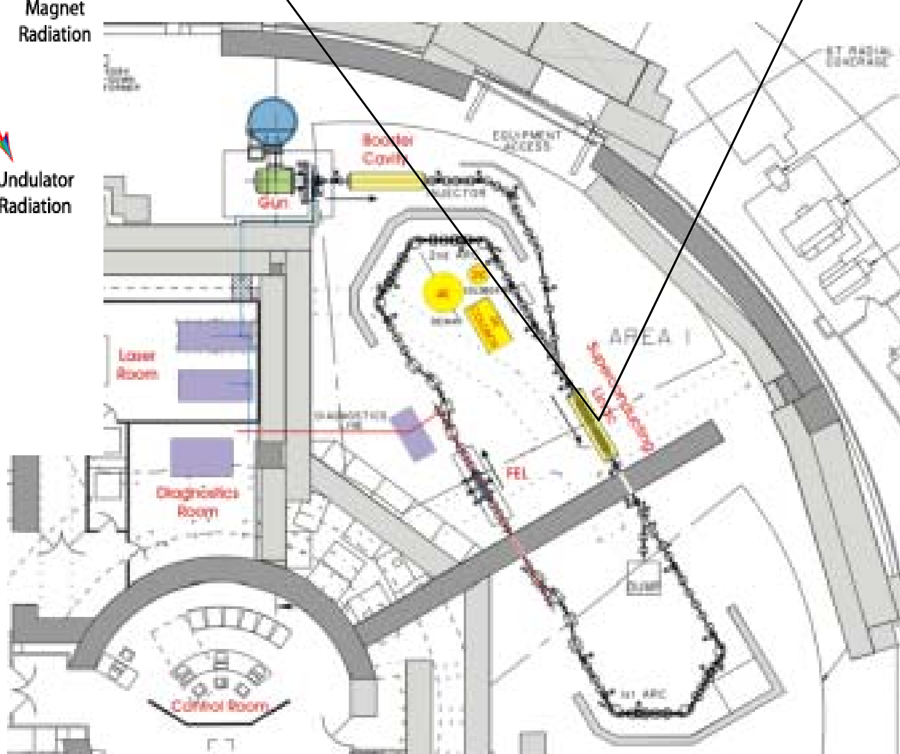
ASTeC
accelerator science and technology centre







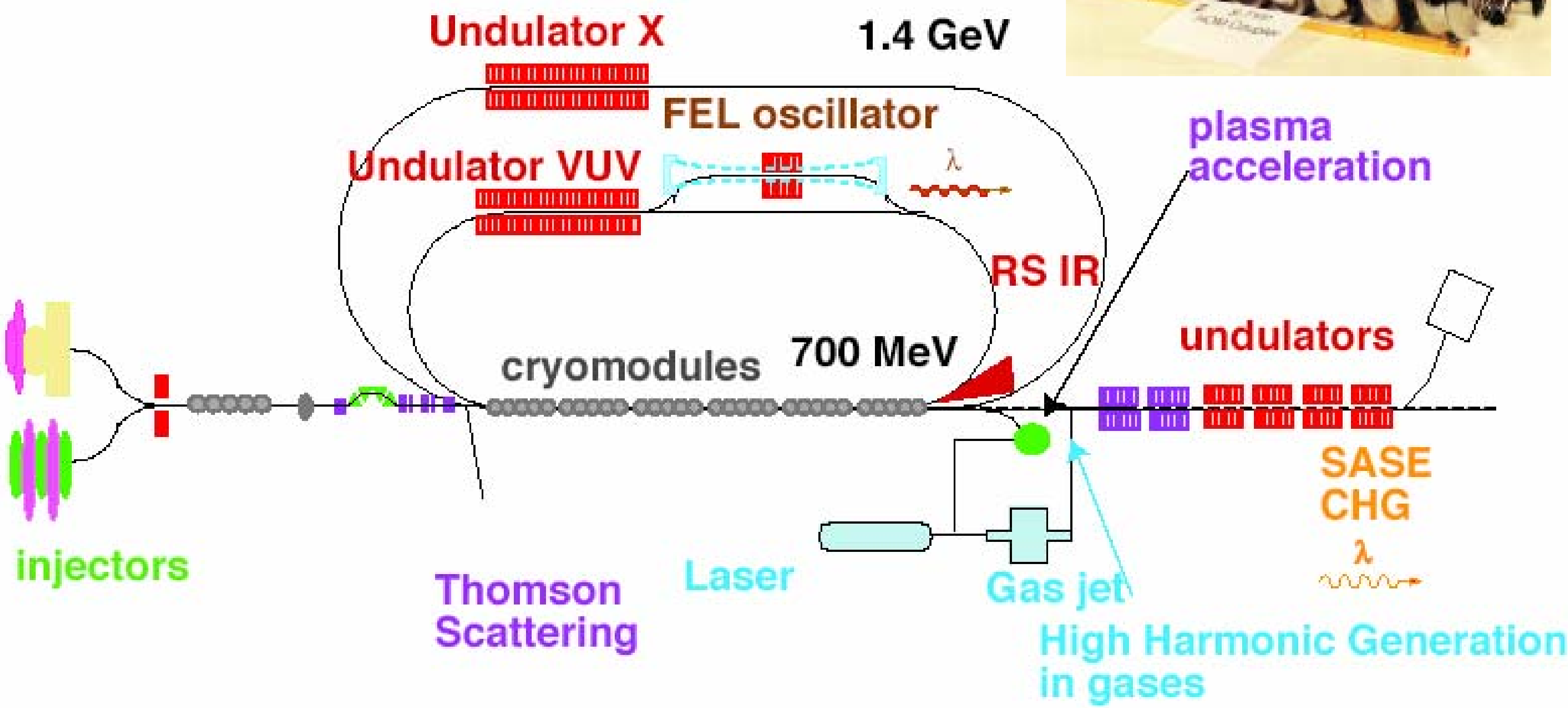
600 MeV



Funded Prototype 30 MeV

ARC-EN-CIEL
Accelerator Radiation Complex for ENhanced Coherent Intense Extended Light

France

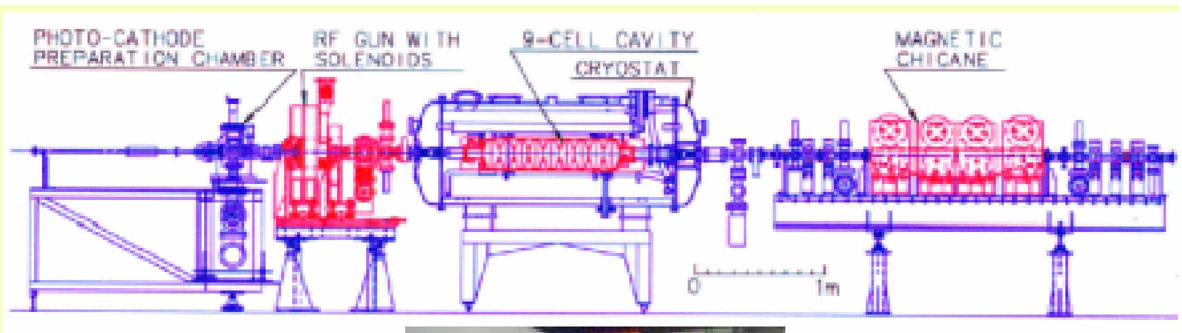


SMTF (SRF Module Test Facility)

- In the US, many TESLA technology-based projects have common or similar systems which could benefit from coordinated efforts.
- In particular, a common module test facility, not available in the US at present.
- Collaborating institutions are:
  - Argonne Laboratory (ANL), Brookhaven (BNL), Cornell University, Fermilab, Jefferson Laboratory (JLAB), Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), MIT-Bates Laboratory, Michigan State University National Superconducting Cyclotron Laboratory (MSU-NSCF), and the Spallation Neutron Source (SNS) at Oak Ridge.
- All these laboratories have efforts in SRF broadly funded by USDOE HEP, Nuclear, Basic Energy Sciences and the NSF.
- Collaborators have had two meetings at Argonne National Labs (Feb & May 04) to develop a joint test facility (SMTF)

- **SMTF could complement TTF and XFEL to help kick-start ILC in USA, if technology choice is cold, and subject to GDI plans.**

S M T F Evolution



2005

A0 injec

One Module, Cryo, RF, no beam

2006

Add Beam

One RF Unit

2008

. . .

ILC Test Bed (possible Proton Driver ??)

Subject to GDI plans

ILC injector

Goals: Use Existing Infrastructure in US Labs/ Develop US Industry

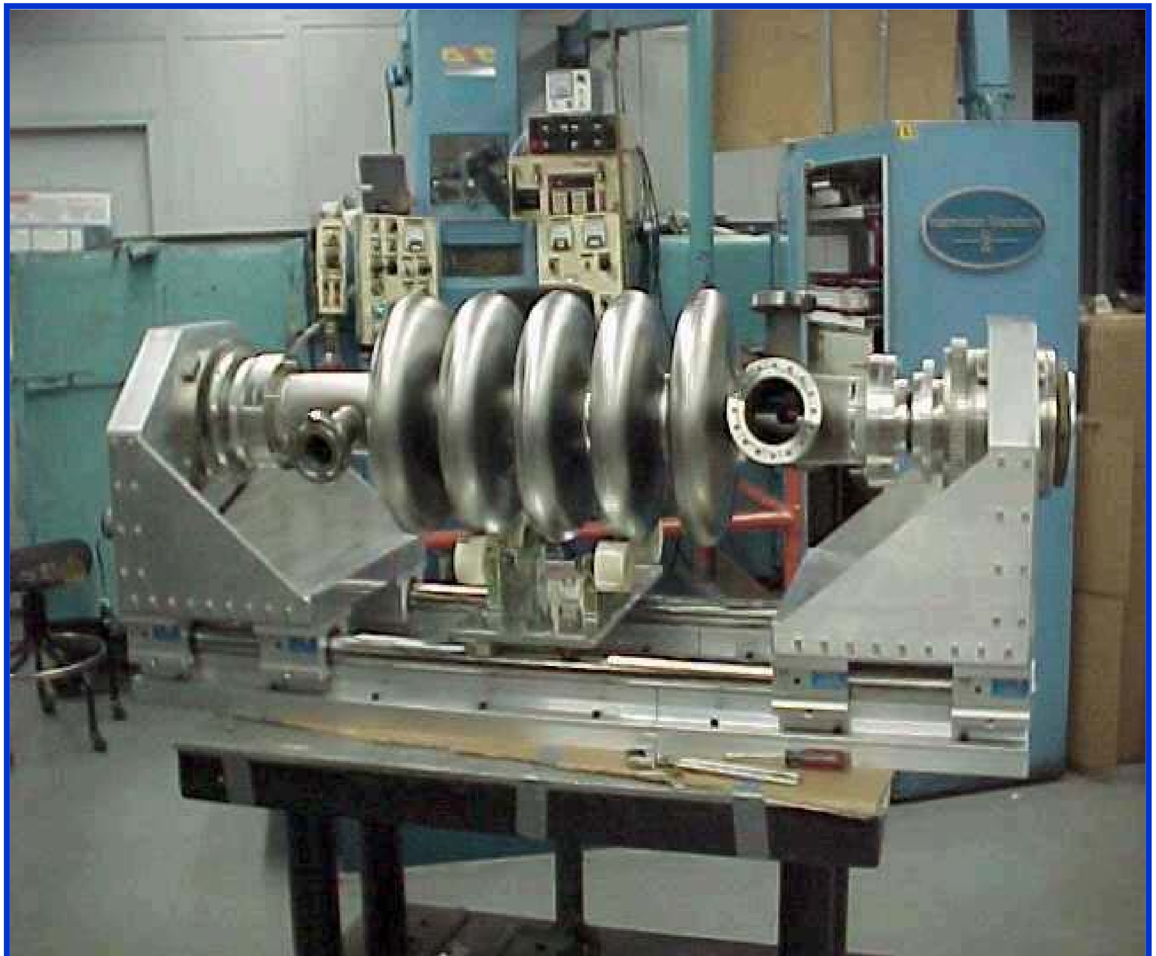
- Fabricate cavities and cryomodule parts in US industry, e.g AES (fast developing SRF Capability)
- Electropolishing at Jlab
- Vertical tests at Cornell/Jlab/LANL
- String and cryomodule assembly at JLAB/LANL
- Bring to SMTF at FNAL

S/C FIVE (5) CELL CAVITY-700MHz RRR250

Advanced Energy Systems, Inc.

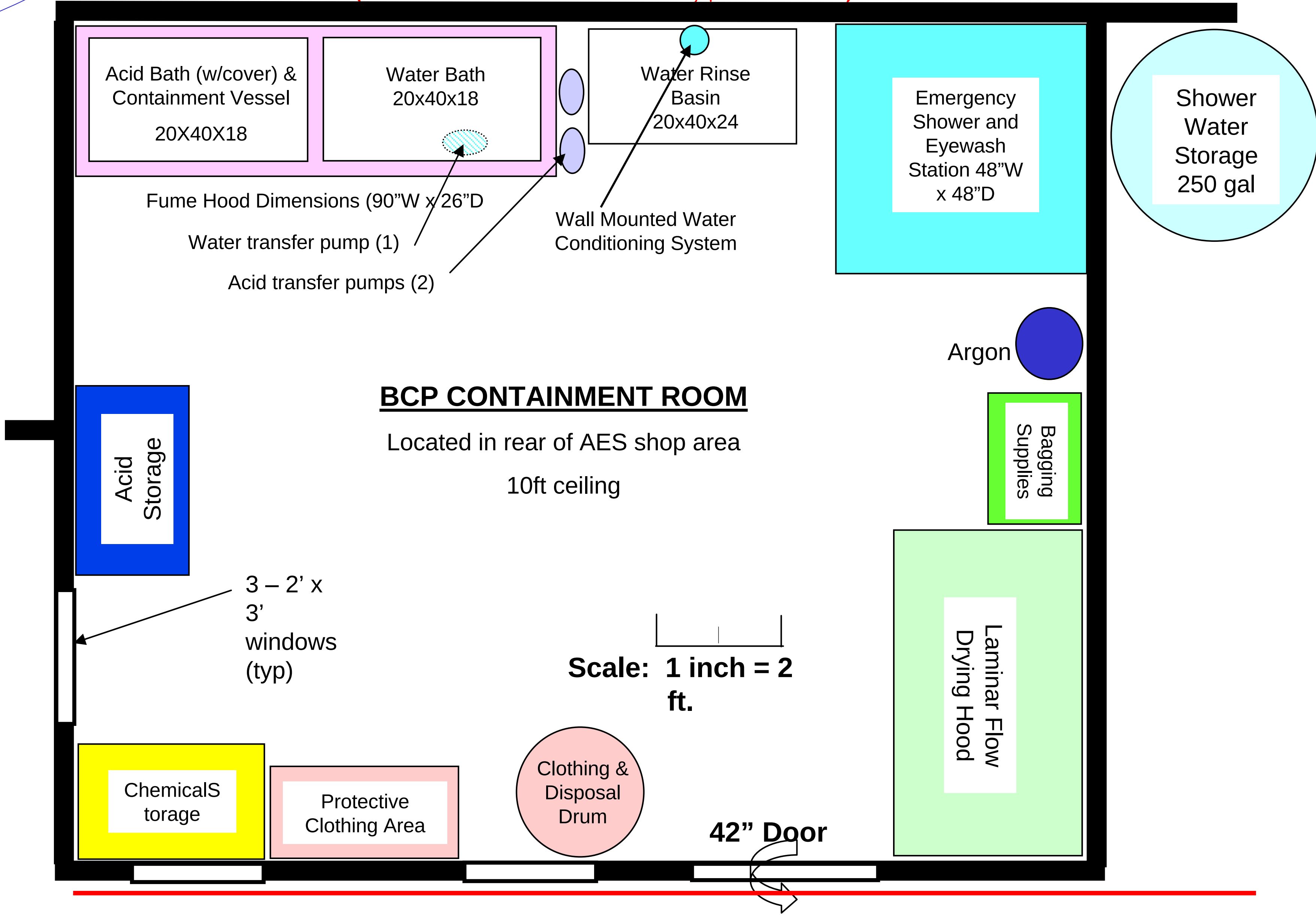
Putting Accelerator Technology to Work

In US



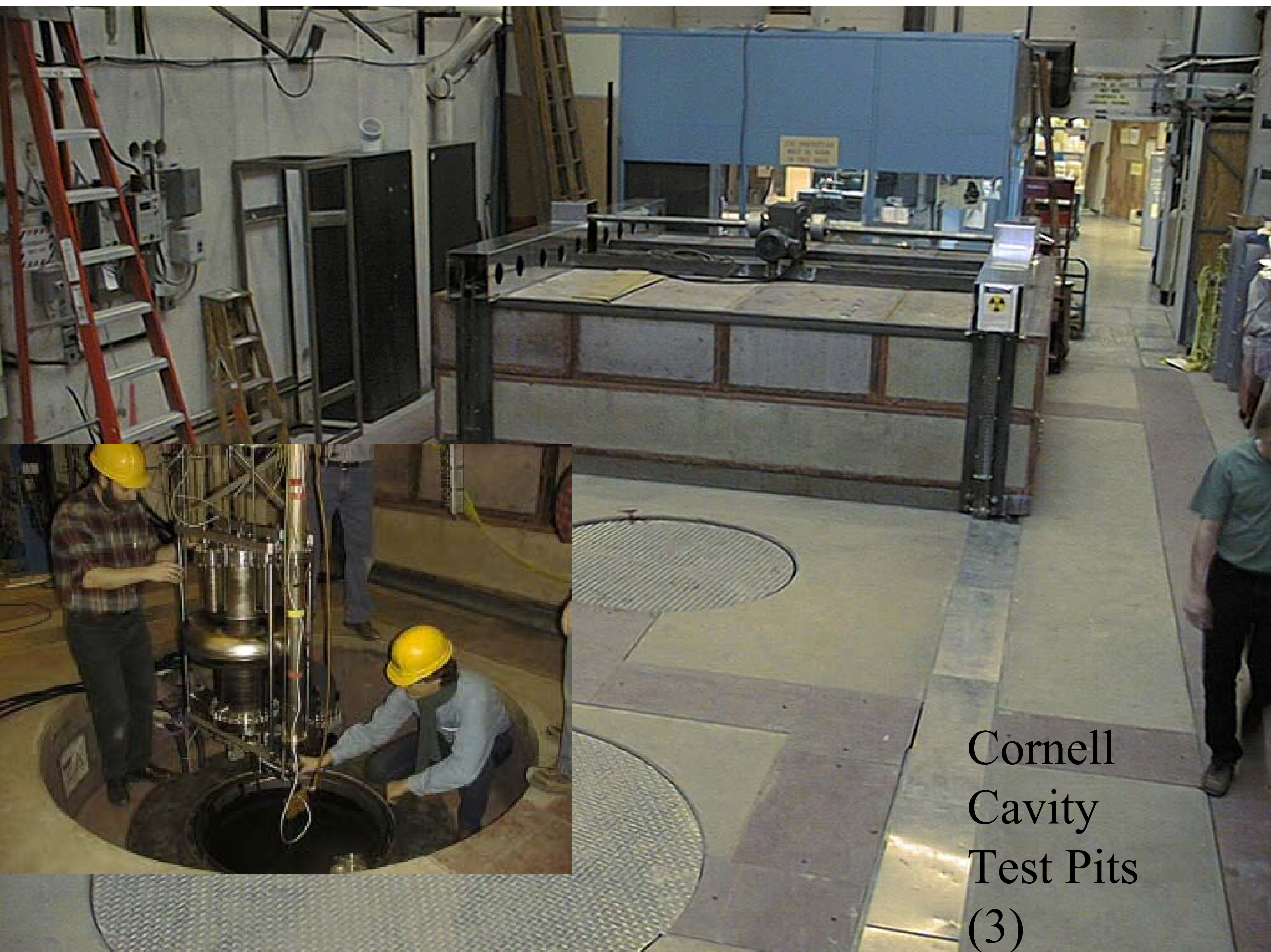
Advanced Energy Systems, Inc.

Plan View of BCP Lab Area at AES (13ft wide X 16ft long - inside)



JLAB

Cavity Vertical Test Areas (6)



Cornell Cavity Test Pits (3)

Jlab - Cryomodule Assembly and Test Areas

Cryomodule Test Facility (CMTF)

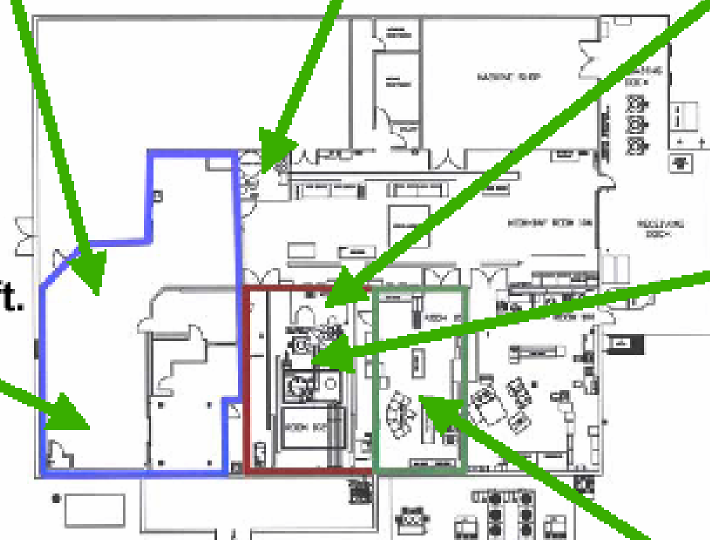
Los Alamos Nat Lab - SRF Facilities

2. Assembly with flanges, couplers, valves, etc. in a 2600 ft^2 Clean room

1. Ultra-pure water is used for HPR and assembly.

3. Set on the cryostat inser

140 ft.



100 ft.

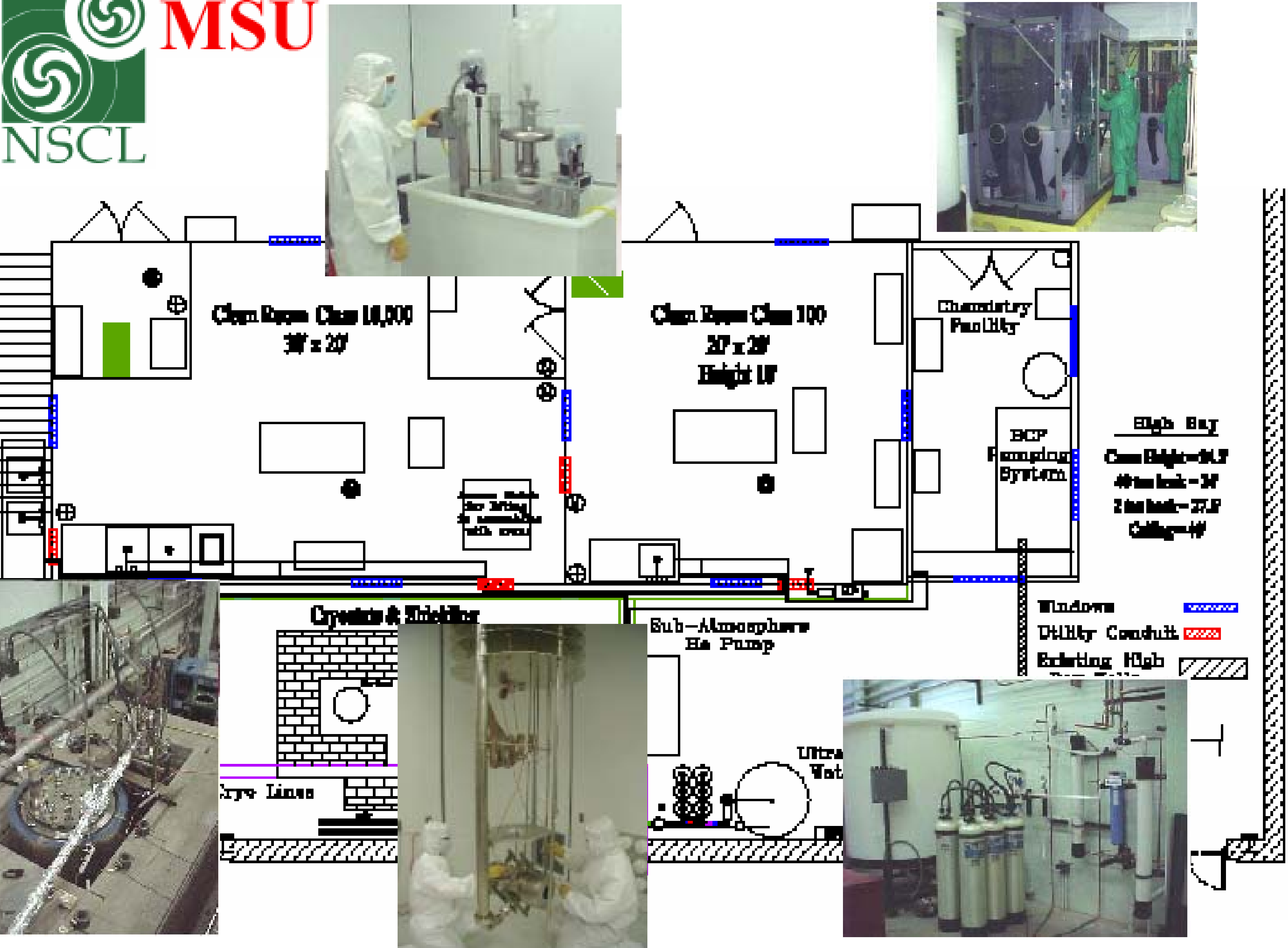
4. Inserted in a 38" cryostat with radiation shield

High-pressure rinsed in a clean room.

Control, tuning

1943 - 2003

MSU
NSCL



Clean Room Class 10,000
Clean Room Class 100
Chemistry Facility
BCP
Pumping System
High Bay
Cryostats & Shielding
Sub-Atmosphere He Pump
Cryo Lines
Windows
Utility Conduit

Meson Area at FNAL

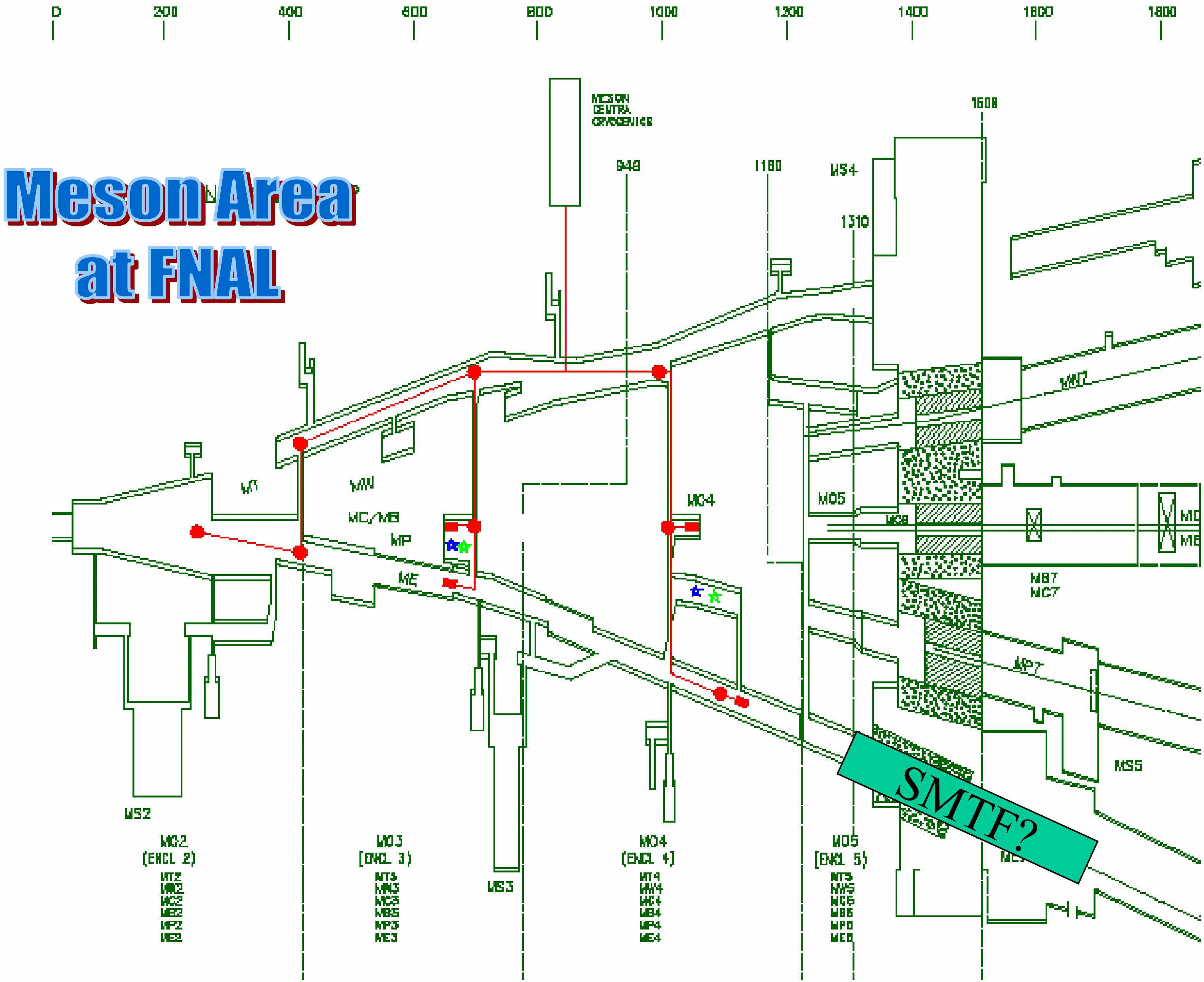


Figure 1 Meson Enclosure Map and Cryogenic Transfer Line Location

Conclusions

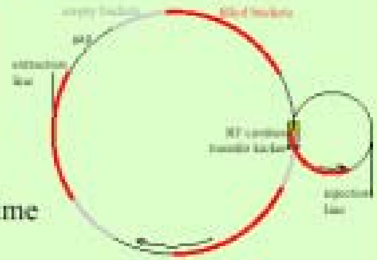
- Two cryomodules with 16 active meters of BCP cavities reached 25 MV/m (> 500 GeV requirement)
  - acceptable alignment tolerance
  - acceptable dark current,
- For upgrade, five 9-cell EP cavities reached 35 - 40 MV/m in vertical tests
  - > Procedures for cavity preparation are well understood, in hand, and reproducible.
  - > Individual cavities can be prepared with low dark current
- Three 9-cell EP units fully equipped with couplers, tuners…tested at full power at 35 MV/m (and higher) in a special 1/8 th module (CHECCIA)
- More than 1000 hours reliable operation at 35 MV/m
  - cavity, couplers, tuners, LF compensation, without trips
- One 9-cell unit tested at 35 MV/m in a full TTF cryomodule
  - > high gradient can be transferred to the complete module
  - >dark currents at 35 MV/m are acceptably low

Conclusions (2)

- Major headstart in industrialization of cavities, couplers, cryomodules, RF power components
- Extensive experience base: 90 cavities tested, 10 cryomodules (80m)
- 20 GeV XFEL momentum strong and important for cold LC
- TESLA technology and momentum propelling a variety of new accelerators
- US collaboration forming to implement TESLA technology to realize new accelerators for NP, BES.

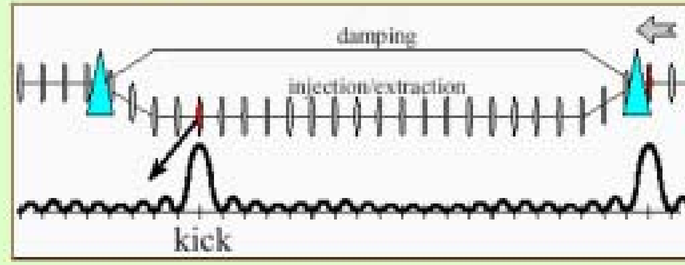
- SMTF could parallel TTF at DESY for ILC start-up activities.

1. multiple bunch trains with intertrain gaps



- always inject and eject the last bunch in a train
- kicker rise time < 6 ns, but fall time can be ~gap length
- beam loading maintained by ~100 m ring with shared RF system
- ~6 km ring filled by transfers of undamped trains from the ~100 m ring

3. Fourier series kicker



- kicker is a series of N transverse RF cavities tuned to frequencies which differ by ~3 MHz.
- proper adjustment of amplitudes and phases kicks one bunch while leaving the next (N-1) undisturbed.
- SCRF + transverse kick minimizes beam-induced fields in cavities.

6 km instead of 17 km

Ib = 444 ma instead of 160 mA

Comparison of dogbone and small ring footprints